

Conceptual Design and Evaluation of Selected Space Station Concepts

VOLUME 1

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National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas

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LIST OF ACRONYMS AND ABBREVIATIONS

BB	Building Block
C/CM	Command/Control Module
CDG	Concept Development Group
CMG	Control Moment Gyro
DDT&E	Design, Develop, Test, and Evaluation
ESS	Energy Storage Subsystem
ET	External Tank
EVA	Extra Vehicular Activity
FF	Free Flyer
HM	Habitation Module
Hz	Hertz (Cycles per second)
IM	Interconnect Module
IOC	Initial Operational Capability
LM	Laboratory Module
LVLH	Local Vertical, Local Horizontal
MAS	Mission Analysis Study
OCZ	Operational Control Zone
OTV	Orbital Transfer Vehicle
OMV	Orbital Maneuvering Vehicle
PCM	Power Conditioning Module
PMAD	Power Management and Distribution
RMS	Remote Manipulator System
RCS	Reaction Control System
SE&I	System Engineering and Integration
SSTF	Space Station Task Force
SOC	Space Operations Center
SOW	Statement of Work
SSCM	Space Station Cost Model
TEA	Torque Equilibrium Attitude
TDRS	Tracking and Data Relay Satellite
WCS	Waste Control System

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CONCEPTUAL DESIGN AND EVALUATION OF SELECTED SPACE STATION CONCEPTS

1.0 INTRODUCTION

1.1 Purpose and Objectives

The purpose of this report is to document the results of a brief special emphasis Space Station Configuration Study conducted at the Johnson Space Center from November 2 to December 16, 1983. The objectives of the study were as follows:

- a. Define candidate Space Station configuration concepts to meet the NASA Headquarters Concept Development Group (CDG) requirements.
- b. Produce engineering and programmatic data on these concepts suitable for NASA and industry dissemination.
- c. Produce a data base for input to the CDG's evaluation of generic Space Station configurations and for JSC use in the critique of the CDG's generic configuration evaluation process.

This special emphasis study represents a temporary focusing and acceleration of a longer term in-house Space Station study, which was initiated at JSC in early 1983 (reference 1-1) and is scheduled for completion in April 1984. The need for temporary focusing and acceleration was prompted by necessity for developing a greater depth of understanding of candidate configurations which existed at the time in support of program and technical planning activities (i.e. SE&I plan and work package options). In addition, this study supports the CDG study task 11 entitled "Alternate Configurations and Controllability." It should be noted that this study is not a general Space Station configuration study aimed toward definition of new and/or optimized Space Station concepts. Rather, specific configuration concepts were selected at the cut-set for refinement of definition to meet the CDG requirements and for

evaluation in terms of selected criteria. Moreover, system and subsystem selections and design approaches were based on trade-off study results from previous studies. In some instances, where trade study results were not available, decisions were made based on engineering judgment to facilitate system definition within the study time allowed. In such instances, the decisions were noted and identified as issues for future study. Also, some inconsistencies in data may exist from section to section due to limited time to iterate results.

The organization of this report is arranged to present the definition and evaluation of each of the candidate concepts on an individual stand-alone basis. Section 2.0 provides an overview description of each configuration concept. Section 3.0 presents functional description and evaluation of each configuration in terms of user, crew, operation, and safety accommodations. Engineering and cost evaluations are also provided in section 3.0. Section 4.0 provides more detailed discussion of subsystem definition and section 5.0 delineates the technical and programmatic issues identified for future study. Section 6.0 provides a listing of the personnel involved in this study.

1.2 Background

JSC has been involved in Space Station study activities, both in-house and contracted for several years. The in-house study activity was intensified shortly after May 20, 1982, when the Space Station Task Force Group (SSTF) was established at NASA Headquarters. The systems working group of the SSTF identified a large number of Space Station "trade studies" within the purview of the system definition (Book 5) activity. JSC supported these trade study activities by performing approximately 30 different system and subsystem studies. The

initial results of these studies have been documented in Book 5 and related documents. To provide a means of conducting these studies in an organized fashion, an in-house Space Station study statement of work (SOW) was produced by the Space Station Project Office and was implemented by the JSC Systems Engineering and Integration (SE&I) Panel organization.

The SOW defined a comprehensive list of system level and subsystem level tasks, including configuration alternatives definition and evaluation. The SOW identified three configuration concepts for study: a modular, building block concept such as the Space Operations Center (SOC), which had been under study at JSC since 1979; a triangular truss structure concept (delta-truss) previously proposed by JSC (reference 1-2) and concepts involving the use of spent STS external tanks (ET), briefly described in reference 1-3. Detailed study of the ET concepts were not undertaken because a brief study indicated limited capability to meet program requirements and excessive cost for the required unique launch system (reference 1-4).

During the course of the study, another truss structure concept with the characteristics of low aerodynamic drag with an earth oriented flight mode was introduced. This concept was identified as the big "T" concept. In addition, the SOW study was expanded to include definition of flight test bed concepts that could be utilized for development testing and subsequently used as elements of an operational Space Station.

The mission and associated system requirements initially utilized for the SOW study were based on an early assessment of the Mission Analysis Study (MAS) results (reference 1-5). The requirements thus developed were generally consistent with the final results of those produced by the MAS contractors; however, when the requirements were synthesized by the Missions Requirements Working Group and subsequently adopted by the CDS during May 1983, several of the

requirements were significantly more demanding than previously indicated by most of the MAS contractors. Figure 1.2-1 shows a summary comparison of the MAS contractor, CDG and baseline in-house study requirements. Note that the CDG requirements for crew size and power are roughly twice those for the MAS and in-house baseline studies.

The special emphasis configuration study, which is the subject of this report, utilized the same basic configuration concepts defined in the SOW study. A major task of the study was to resize the configurations and to rearrange and augment elements of the configurations to meet the current Headquarters CDG requirements shown in figure 1.2-2. In summary, the configuration concepts selected for this study and their primary unique characteristics are outlined below.

- o Building Block (BB)

- Built up by interconnecting of essential elements, i.e., minimum hardware launch to orbit

- Modules earth oriented

- Solar arrays sun tracking

- o Delta Truss

- Rigid overall configuration

- Area available on truss substructure for affixing hardware/mission equipment

- Near solar inertial flight orientation.

- o Big-T Truss

- Stiff overall configuration

- Area available on truss substructure for affixing hardware/mission equipment.

- Modules near earth oriented

- Gravity-gradient flight orientation
- Minimum drag orientation solar array (streamline), solar array semi solar oriented.

MISSION REQUIREMENTS SUMMARY (IOC/GROWTH)

	MAS	CDG	IN-HOUSE BL
CREW SIZE	3-5/8-12	8/14	3/7
POWER (KW)	20-30/60-80	75/150	30/50
ATTACHED PYLDS (PORTS/MOUNTS)	R&E LAB/ SEVERAL LABS	YES/+RES. (4 MOUNTS)	1/4
R&D LAB (PRESS. VOL.)	120M ³	120M ³	(100M, GROWABLE)
SMART TMS	---/YES	YES	NOT CONSIDERED
ORBIT	LOW INCL. 200-270 NM	28.5	28.5 -- 270NM
PLATFORM/FF	1 PLATFORM (HIGH INCL) POST IOC	PLATFORMS (15KW) POLAR-28.5	NOT CONSIDERED
SPACE BASED OTV	EXPENDABLE/ SB AEROBRAKED	---/YES (IOC)	NOT CONSIDERED
DATA	---	100 MBPS	TBD
ORIENTATION REQUIRED	VARIABLE	?	SOC-EARTH ORIEN. TRUSS-SOLAR

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2.0 CONCEPT OVERVIEW

2.1 Summary

Three configuration concepts have been defined for evaluation in this study: the building block, delta and the "T." Each concept emphasizes a different set of design drivers.

The building block concept attempts to minimize structure and subsystem hardware. It uses the pressurized modules as the structural foundation of the station. The core station is earth-oriented and the solar arrays, mounted on booms, are oriented toward the sun.

The delta uses a triangular truss structure for independent attachment of station elements to maximize rigidity and enhance controllability and mission versatility. The delta is approximately solar-oriented with the array, mounted on one face of the triangle, at a constant angle to the orbit plane to eliminate secular gravity gradient torques. Solar orientation simplifies thermal control.

The "T" minimizes aerodynamic drag by maintaining the array parallel to the velocity vector. It also uses a truss structure for enhanced rigidity, element independence, and mission versatility. The "T" is earth-oriented and is arranged for gravity gradient stability. The solar array is approximately twice as large as a fully sun oriented array. The CDG requirements shown in figure 1.2-1 were interpreted as requiring the module lengths, viewing requirements, etc., as shown in figure 2.1-1 for the purposes of defining concepts for this study.

FIGURE 2.1-1

CONFIGURATION DRIVING REQUIREMENTS

	<u>LOC</u>	<u>GROWTH</u>
PRESSURIZED MODULES (SEGMENTS)		
HAB (8 -- 14)	40 FT.	70 FT. (EQUIVALENT)
COMM/CONTROL	20 FT.	2 x 20 FT.
LABS	2 x 20 FT.	120 FT (EQUIVALENT)
OBSERVATIONS		
EARTH	LAB & RACK	LAB & RACK
SOLAR	RACK	RACK
STELLAR	RACK	RACK
POWER & COOLING (BUSS)	75 KW	150 KW
ORBIT MAINTENANCE	270K MI	270K MI
OMV	ONE WITH HANGAR 14,000 LB. FUEL	TWO WITH HANGAR 28,000 LB FUEL
OTV	NONE	TWO WITH HANGARS 100,000 LB. FUEL
SATELLITES	ONE WITH HANGAR EXTERNAL RACK SPACE	ONE WITH HANGAR EXTERNAL RACK SPACE

2.2 Building Block Configuration

2.2.1 General Arrangement

The building block concept utilizes the pressurized modules as a structural base to which the component parts of the station are attached. The pressurized modules at IOC (figure 2.2-1) are arranged in a quadrangle for safety and efficient internal crew movement. Electrical power generation and conditioning, radiators and antennas are mounted on two booms perpendicular to the plane of the quadrangle.

The growth configuration (figure 2.2-2) adds two quadrangles of pressurized modules. Additional power and radiator components are mounted on the existing booms.

Hangars, manipulators, and other external elements are attached to berthing ports at the corners of the quadrangles.

2.2.2 Function/Operation

The normal attitude of the building block configuration places the pressurized modules in the orbit plane with the long dimension of the quadrangle vertical (see Figure 2.2-3). This is intended to provide gravity gradient stability, provide approach paths for the Orbiter, OMV and OTV, and permit adequate earth and celestial viewing. Reorientation in pitch is required for orbit reboost because of the thruster location.

Two Orbiter berthing ports are provided. These are shown in figure 2.2-1 for IOC and 2.2-2 for the growth version. Ports are also available for installation of temporary modules in addition to manipulators, hangars, etc.

2.2.3 Elements

The building block concept comprises a number of pressurized and unpressurized modular elements, arranged as shown in figures 2.2-1 and 2.2-2.

2.2.3.1 Command/Control Module (C/CM)

The C/CM is the primary command and operations work station. It also provides crew support in the event of functional loss of the habitation module in the IOC phase. The C/CM is arranged as illustrated in figure 2.2-4. Berthing mechanisms are installed at both ends. Overall length between berthing interfaces is 264", to provide volume for avionics and contingency crew accommodation and to maintain a standard module length for assembly versatility. One C/CM is required at IOC; a second C/CM is added in the growth station.

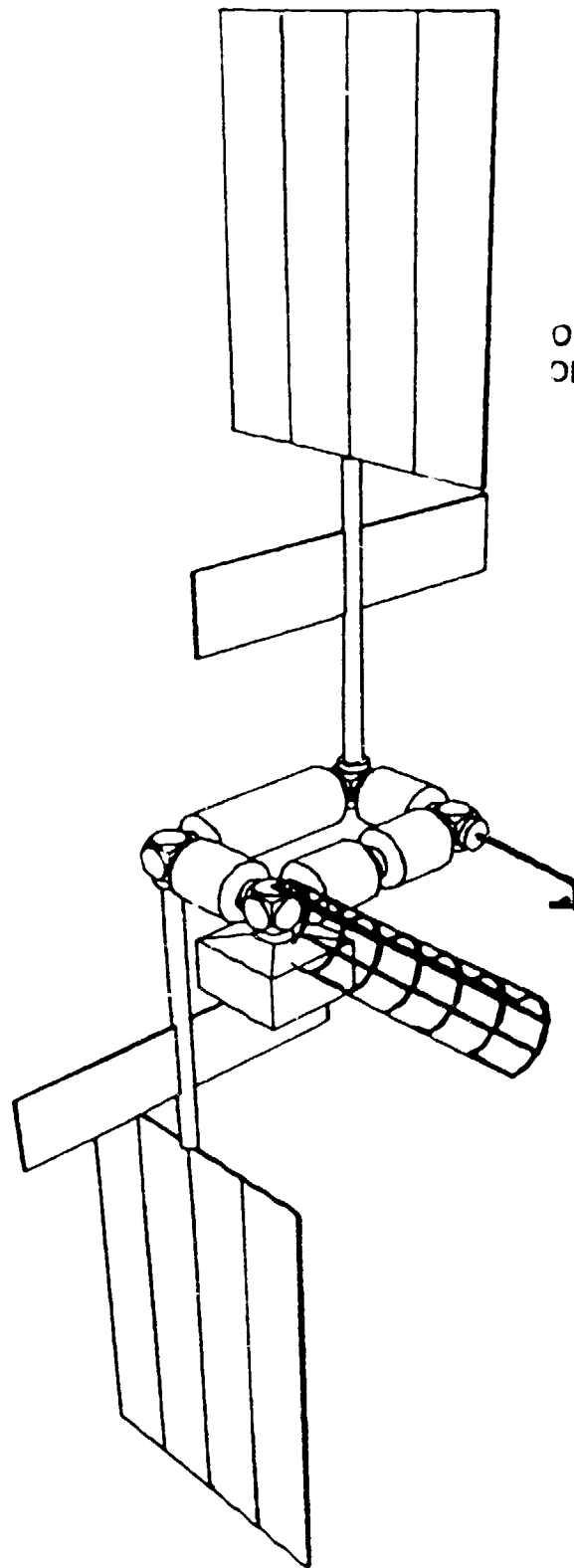
2.2.3.2 Habitation Module (HM)

The HM (figure 2.2-5) is the primary location for all crew support functions, including food, hygiene, waste management, health maintenance, sleep, and recreation for a crew of eight. A minimal command station provides backup capability in case the C/CM becomes unusable. Overall length between berthing interfaces is 528", or twice that of the C/CM. The IOC station includes one HM and the growth station two.

2.2.3.3 Laboratory Module (LM)

The LM provides a pressurized facility for scientific, developmental and production activities on the station. It includes interfaces with station utilities such as electrical power, thermal control, data management, communications and life support. It also provides structural mounting for interior user equipment. It is built in two sizes which are structurally identical to the C/CM and HM respectively. This permits a late choice between

BUILDING BLOCK 10C



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Figure 2.2-1b

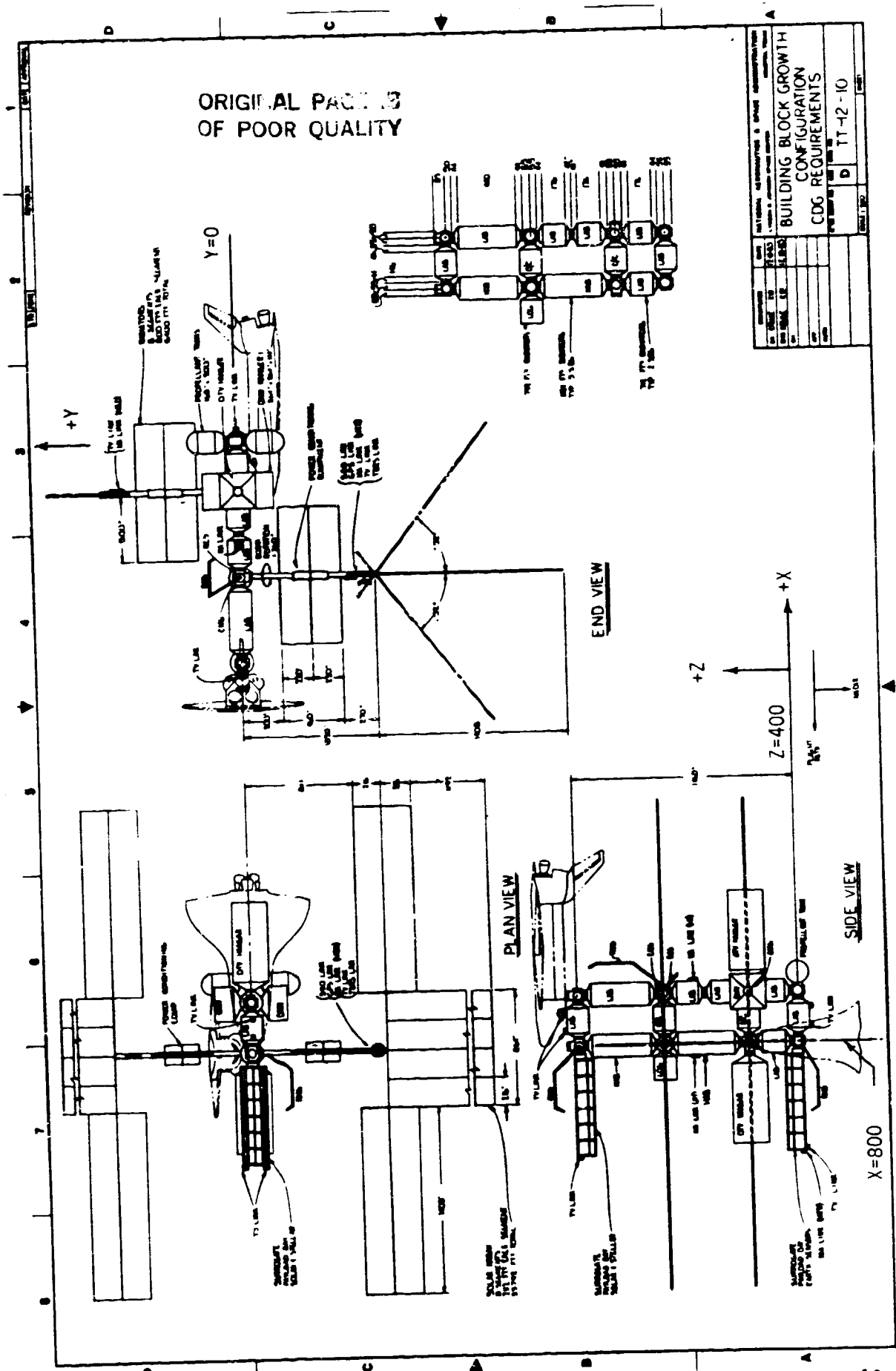


Figure 2.2-2a

BUILDING BLOCK
FINAL CONFIGURATION

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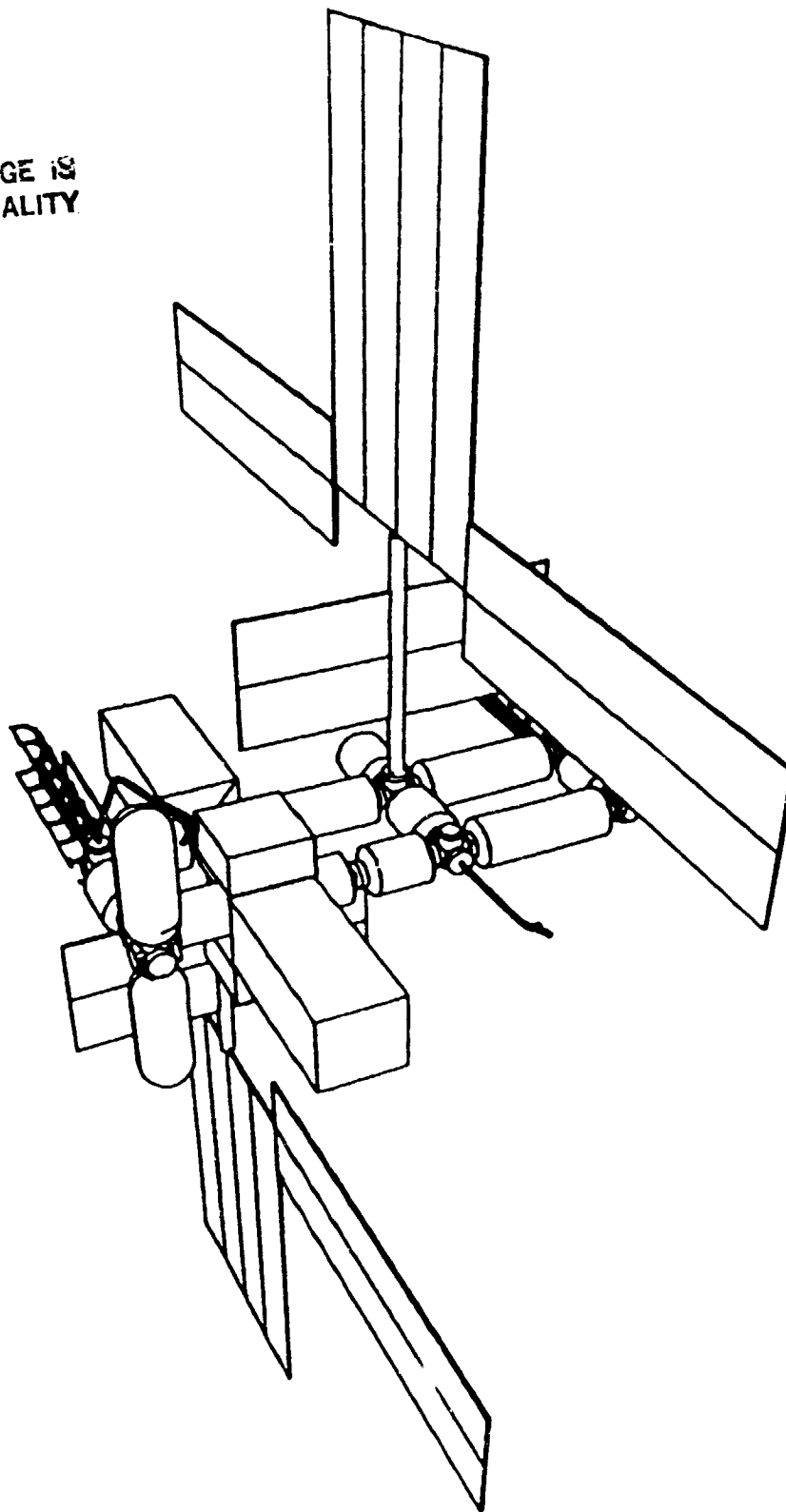


Figure 2.2-2b

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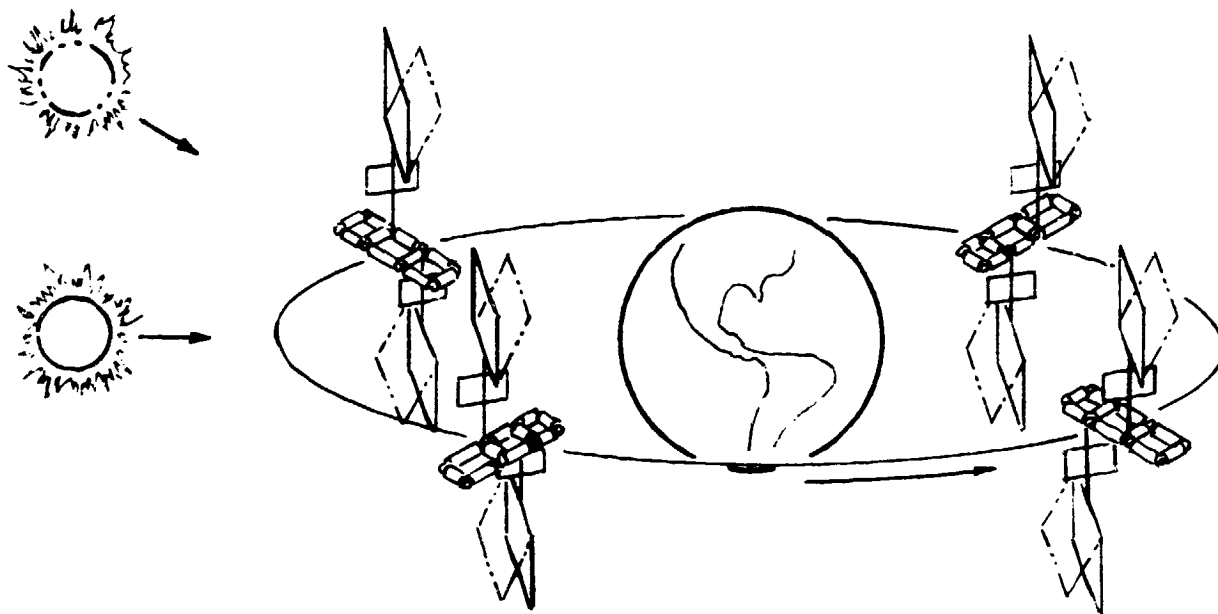
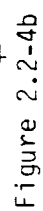
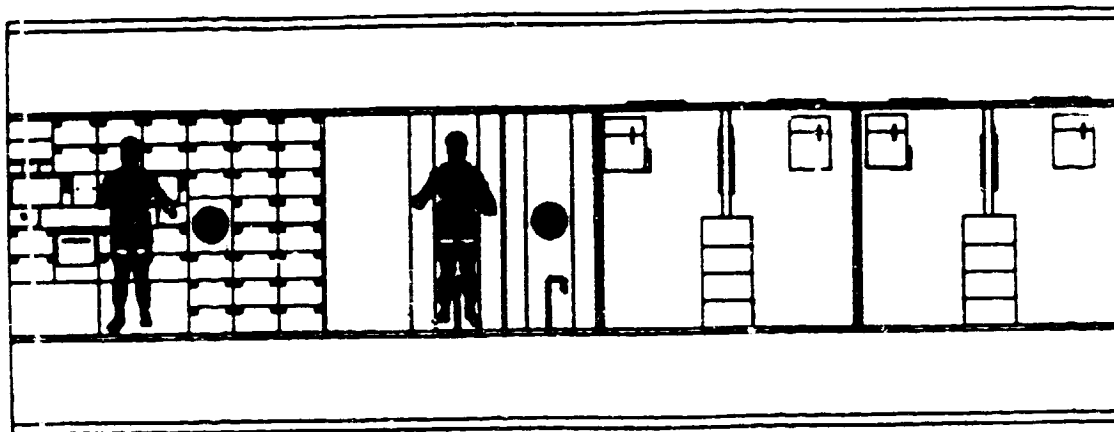


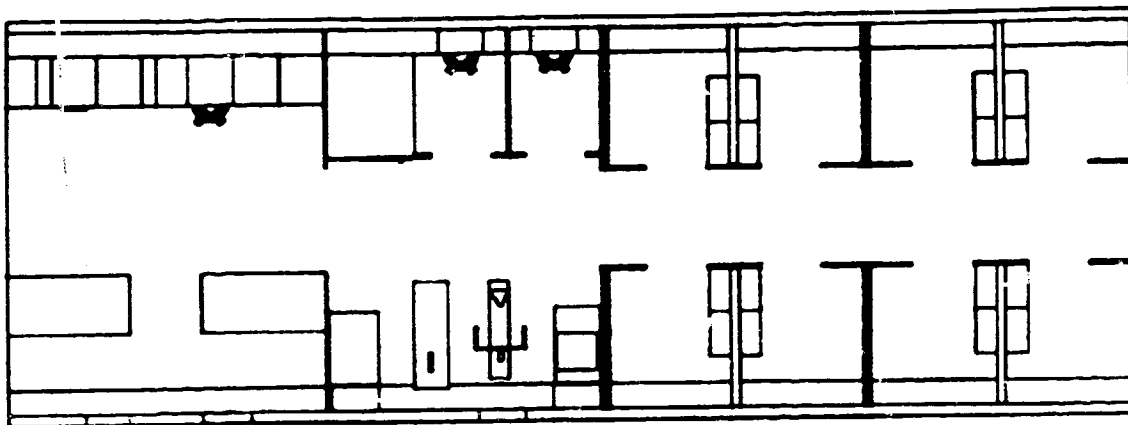
Figure 2.2-3. Building Block Orientation



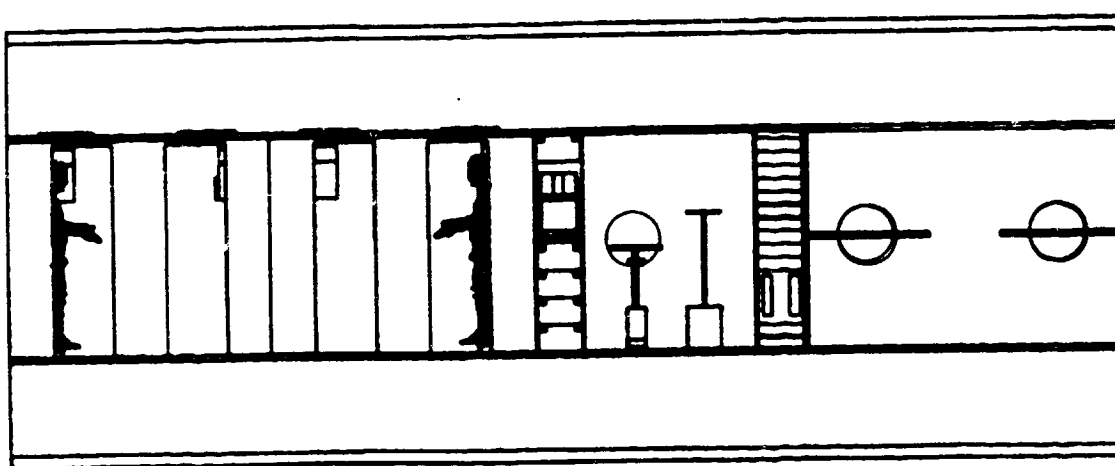


LEFT SIDE VIEW

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PLAN VIEW



RIGHT SIDE VIEW

Figure 2.2-5a Habitation Module 1

the adaptability of smaller modules and the structural efficiency and internal volume of the larger module because two short LM's can be replaced in the configuration by one long LM or vice versa. Two short LM's are provided in the IOC station. Four short LM's and one long LM are added in the growth phase. This is two small LM's in excess of the specified requirement in the growth station; the additional LM serves to close the module quadrangles and avoid the development of a special tunnel.

2.2.3.4 Interconnect Module (IM)

The IM (figure 2.2-6) serves primarily as a means of connecting station elements at right angles without wasting valuable volume in the 14 ft. diameter modules for side ports. The IM has six orthogonal berthing ports that can interchangeably accommodate the Shuttle Orbiter, pressurized station modules, manipulators, hangars, and other station elements. It can also be equipped as an airlock for two crewmen. Four IM's are required on the IOC station and four more on the growth version.

2.2.3.5 Logistics Module

The logistics module serves as a carrier for supplies and equipment brought from earth and for products and waste material to be returned. It is structurally similar to the C/CM with a single berthing port on one end and a rack for tanks and other external stores on the other end.

2.2.3.6 Electrical Power Unit

The electrical power generation subsystem is built in modular form to facilitate installation. Each unit consists of solar array packages, energy storage and conversion units, and a dedicated thermal control subsystem capable of supplying 37.5 KW of electrical power continuously. Two units are included in the IOC configuration and four in the growth configuration.

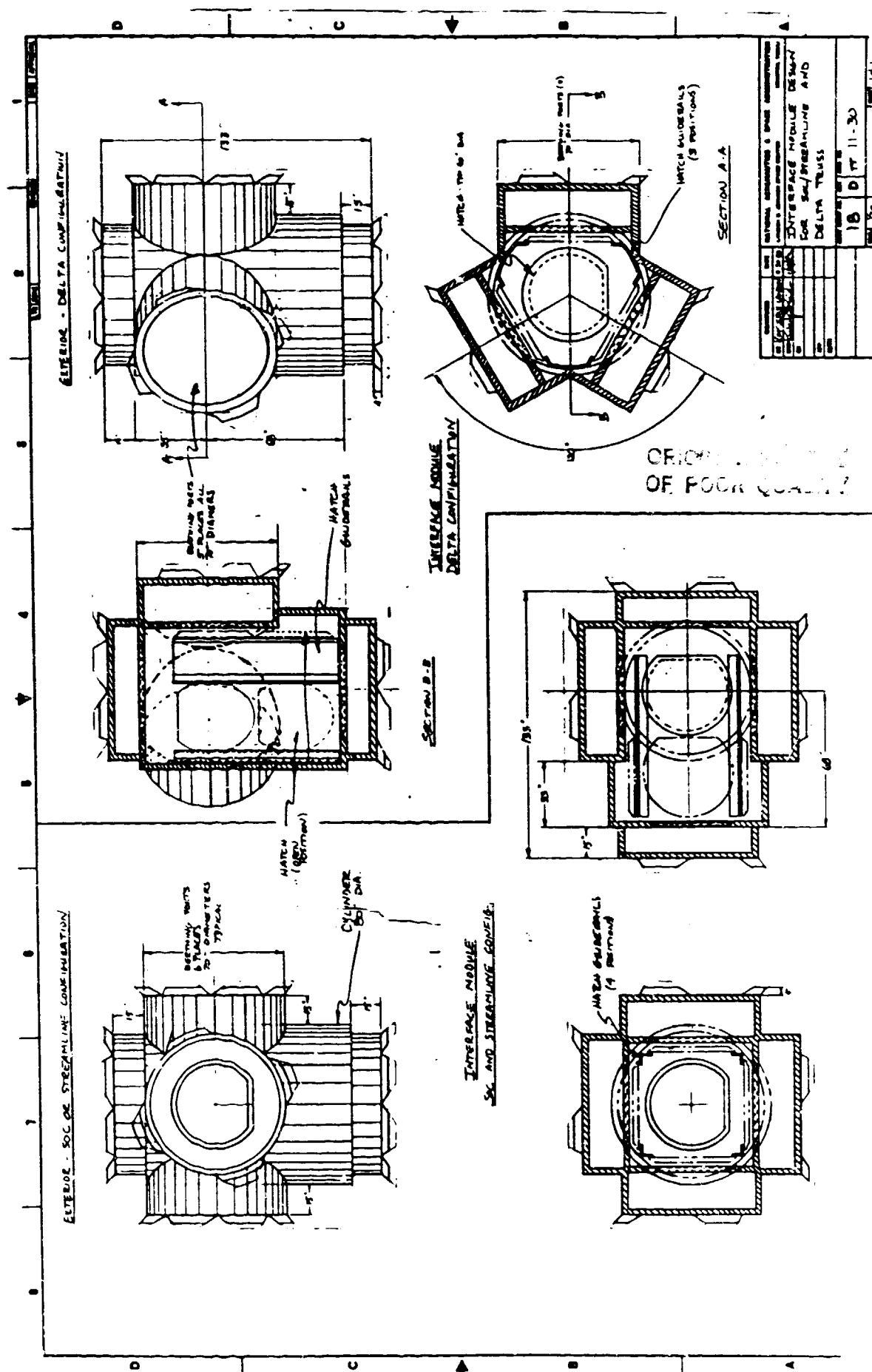


Figure 2.2-6

2.2.3.7 Boom

Two booms attached to IM's in the IOC phase provide mounting points and two-axis orientation for the power system, radiators, and antennas. The additional components for the growth phase are mounted on the same booms.

2.2.3.8 Manipulator

An Orbiter-type RMS mounted on a standard berthing mechanism and controlled remotely from the C/CM is used to transport massive items from place to place on the station and to assist the Orbiter RMS in station assembly and resupply. One RMS is provided at IOC and three in the growth phase.

2.2.3.9 Vehicle Support Facilities

Vehicle support facilities include unpressurized hangars for servicing and protected storage, propellant storage and transfer facilities, and equipment and spares for checkout and maintenance. The IOC capability includes provisions for one OMV. In the growth station, two OMV's and two OTV's can be accommodated.

2.2.3.10 Satellite Service Structure

The satellite service structure provides structural and utilities support for unpressurized user payloads and free flying satellites. One structure is included at IOC, and a second is added in the growth phase.

2.2.4 Subsystem Distribution

The table below summarizes the location of subsystem components within the station.

SUBSYSTEM COMPONENT LOCATION SUMMARY

	C/CM	HM	LM	LOG.	IM	BOOM
ECLSS	X	X	X	/	-	-
THERMAL CONTROL	X	X	X	X	/	X
PROPULSION/RCS	X	-	-	-	-	-
COMM/TRACKING	X	/	/	/	/	X
DATA MANAGEMENT	x	(X)	/	/	/	/
ELECTRICAL POWER	/	/	/	/	/	X
MECHANISMS	X	X	X	X	X	X
CREW ACCOMMODATIONS	(X)	X	/	/	/	-
GNC	X	(X)	-	-	-	-

X PRIMARY LOCATION OF MAJOR COMPONENTS

(X) BACKUP LOCATION OF MAJOR COMPONENTS

/ LOCATION OF SOME MINOR COMPONENTS

- NO SUBSYSTEM COMPONENTS

2.2.5 Mass Properties

The estimated mass properties of the building block configuration are summarized in the following table. Element weights include associated subsystems. Although these estimates do not include an allowance for weight growth, some growth can be expected to occur. This would increase the weights and inertias given, but would not appreciably alter the relative magnitudes of the inertias. See figure 2.2-2 for coordinate system definition.

BUILDING BLOCK

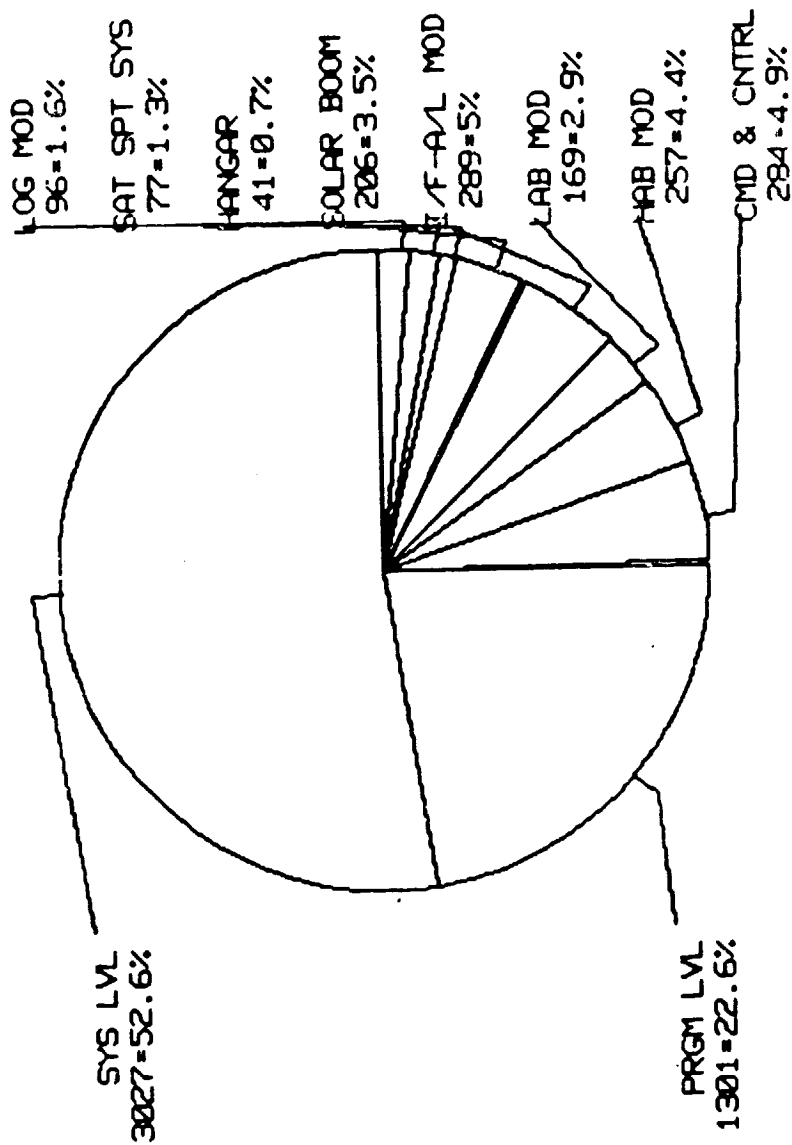
	UNIT MASS LB.	IOC	QUANTITY GROWTH
C/CM	27,700	2	2
HM	51,300	1	2
SINGLE LM	27,700	2	6
DOUBLE LM	51,300	-	1
IM	11,300	4	8
LOGISTICS	27,700	1	1
POWER SYSTEM	8,050	2	4
BOOM	580	2	2
MANIPULATOR	2,000	1	3
OMV HANGAR	3,600	1	2
OTV HANGAR	7,100	-	2
OTV PROP. TANK	6,600	-	1
SATELLITE SVC. STR.	5,200	1	2

	IOC	GROWTH	
		W/O OTV PROP.	W/OTV PROP.
MASS, LB	263,060	571,360	697,360
C.G., IN. X	946.5	950.2	1,020.2
Y	-0.6	-0.8	-0.7
Z	1,114.1	1,180.3	1,040.2
$I_{xx}, 10^6 \text{ SLUG-FT}^2$	9.316	41.063	55.925
I_{yy}	6.769	40.230	57.262
I_{zz}	8.392	14.388	19.054
I_{xy}	0.047	0.016	0.023
I_{xz}	-1.001	-1.067	-7.853
I_{yz}	-1.291	-1.947	-1.962

2.2.6 Cost Overview Building Block Configuration

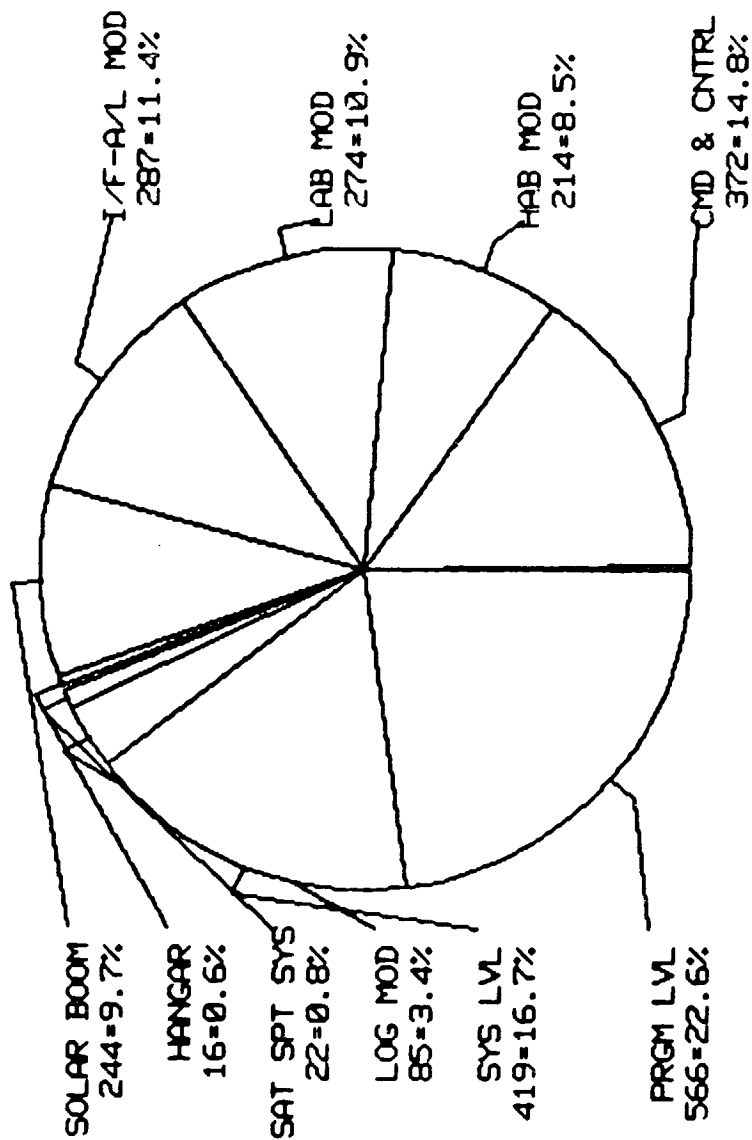
The cost of the BB configuration is \$8.2 billion in 1984 dollars at IOC. The groundrules and assumptions on which this cost is based are discussed in section 3.2.6.1. Figures 2.2.6-1 and 2.2.6-2 show the breakout of the \$8.2 billion for the DDT&E phase and production phase, respectively. It is immediately evident that the majority of the cost of the program is in "overhead" costs, such as system level and program level tasks. Approximately 75% of the DDT&E costs are in this category, contrasted to approximately 25% for hardware development. Roughly 40% of the production costs are system and program level costs, leaving approximately 60% actual hardware production.

FIG. 2.2.6-1
BLDG BLOCK CONFIGURATION
DDTE COST SUMMARY BY MODULE



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FIG. 2.2.6-2
BLDG BLOCK CONFIGURATION
PROD COST SUMMARY BY MODULE



2.3 Delta Concept

2.3.1 General Arrangement

In the delta concept, the functional elements of the station are mounted on a large deployable triangular truss structure for maximum rigidity. One face of the structure is covered by solar arrays. The other two faces support radiators, power conditioning equipment, experiments, payloads, etc.

Pressurized modules are mounted on the truss opposite the solar arrays in two parallel rows.

At IOC, the pressurized modules form a quadrangle at one end of the truss (see figure 2.3-1). A tunnel is used to close the quadrangle.

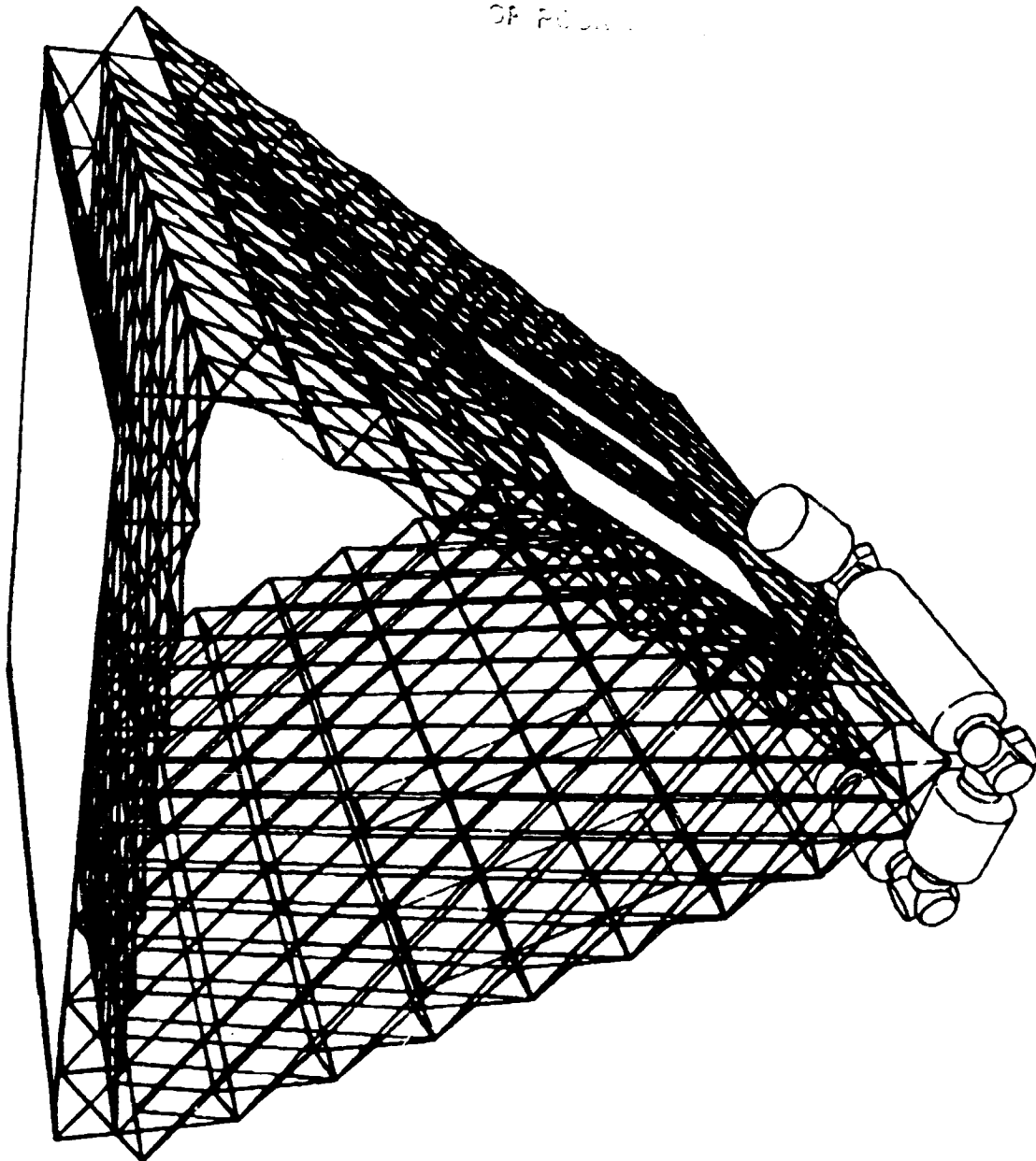
The growth phase (figure 2.3-2) doubles the length of the solar array truss and adds short extensions to the other two sides for rigidity and to support power system radiators. Pressurized modules are added to the IOC set to fill the edge of the truss.

Hangars are located within the triangle to use the truss as primary structure and the radiators as part of the hangar skin.

2.3.2 Function/Operation

The delta configuration is approximately solar oriented with the Y principal axis (figure 2.3-1) perpendicular to the orbit plane. Gravity gradient torques in roll and yaw are therefore nulled; pitch torque is cyclic and can be absorbed by control moment gyros. Mass distribution is such that the Y principal axis is approximately 20° from the Y body axis. From March to September, the solar array is tilted toward the north to minimize the solar angle of incidence (see figure 2.3-3). The array is oversized by 11% to compensate partially for angle of incidence losses. At the equinox, a posigrade maneuver is executed (A in figure 2.3-3) to place the station in a

DELTA TRUSS IOC



DELTA TRUSS IOC

Figure 2.3-1b

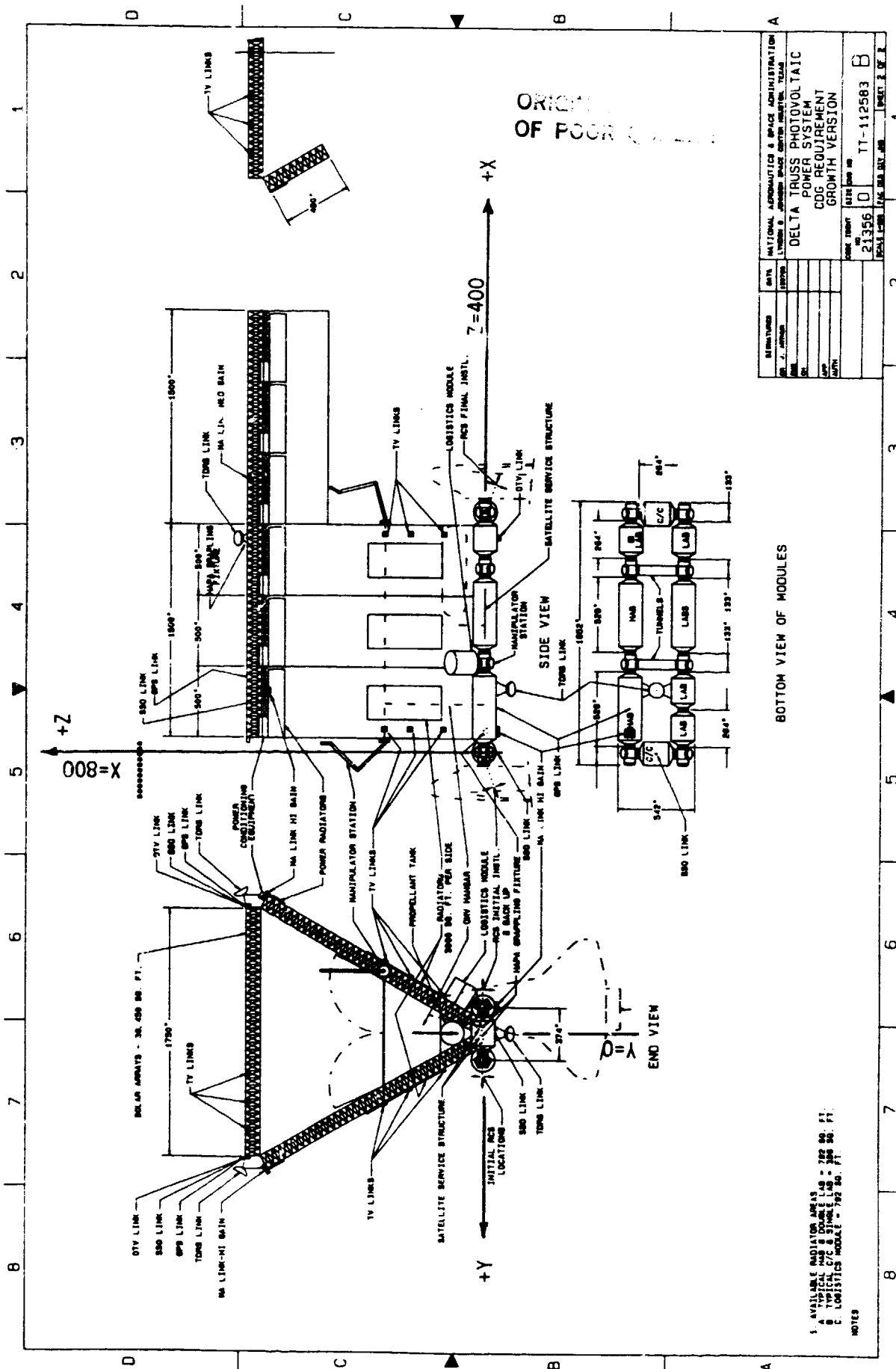


Figure 2.3-2a

DELTA TRUSS BUILD-UP

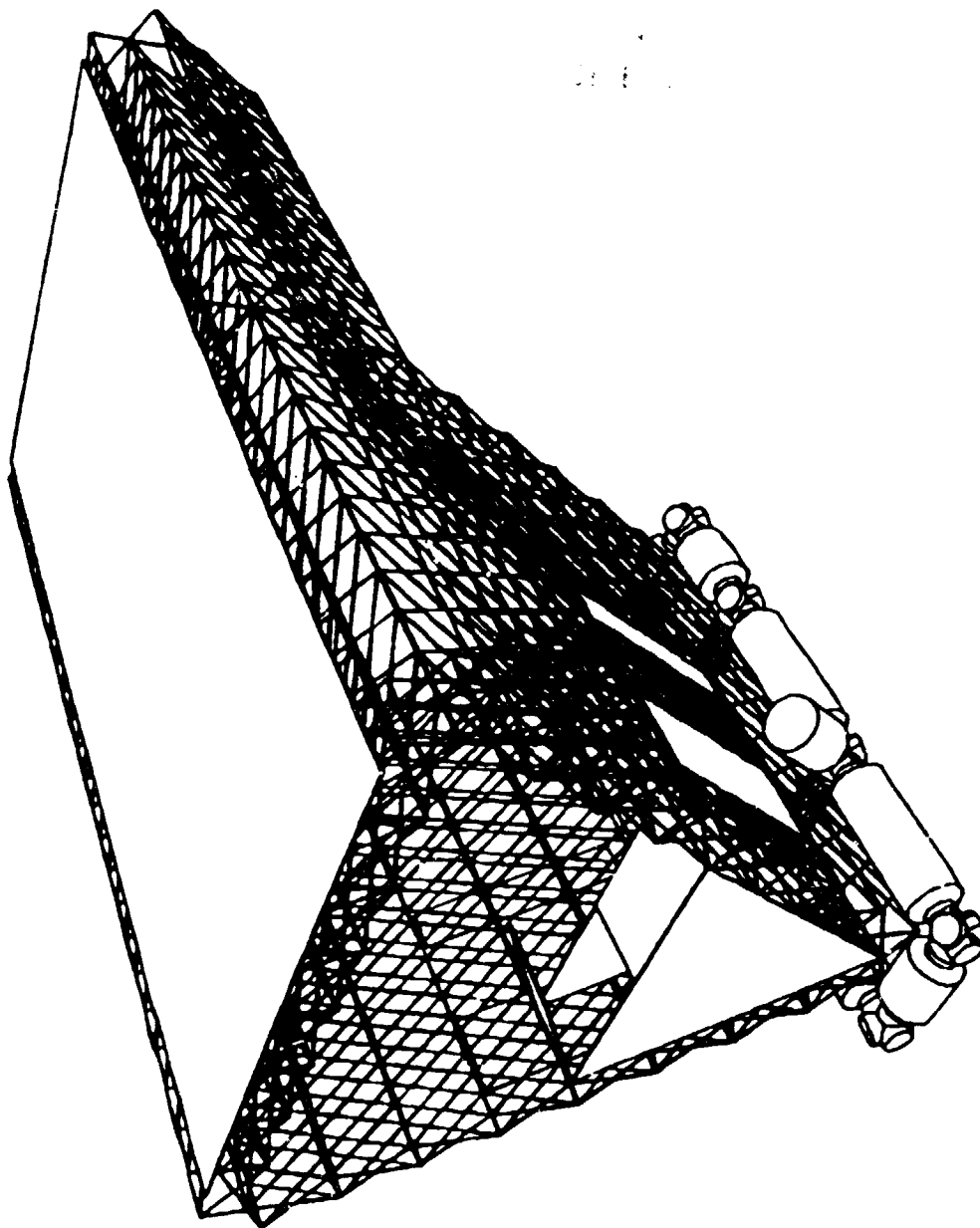


Figure 2.3-2b

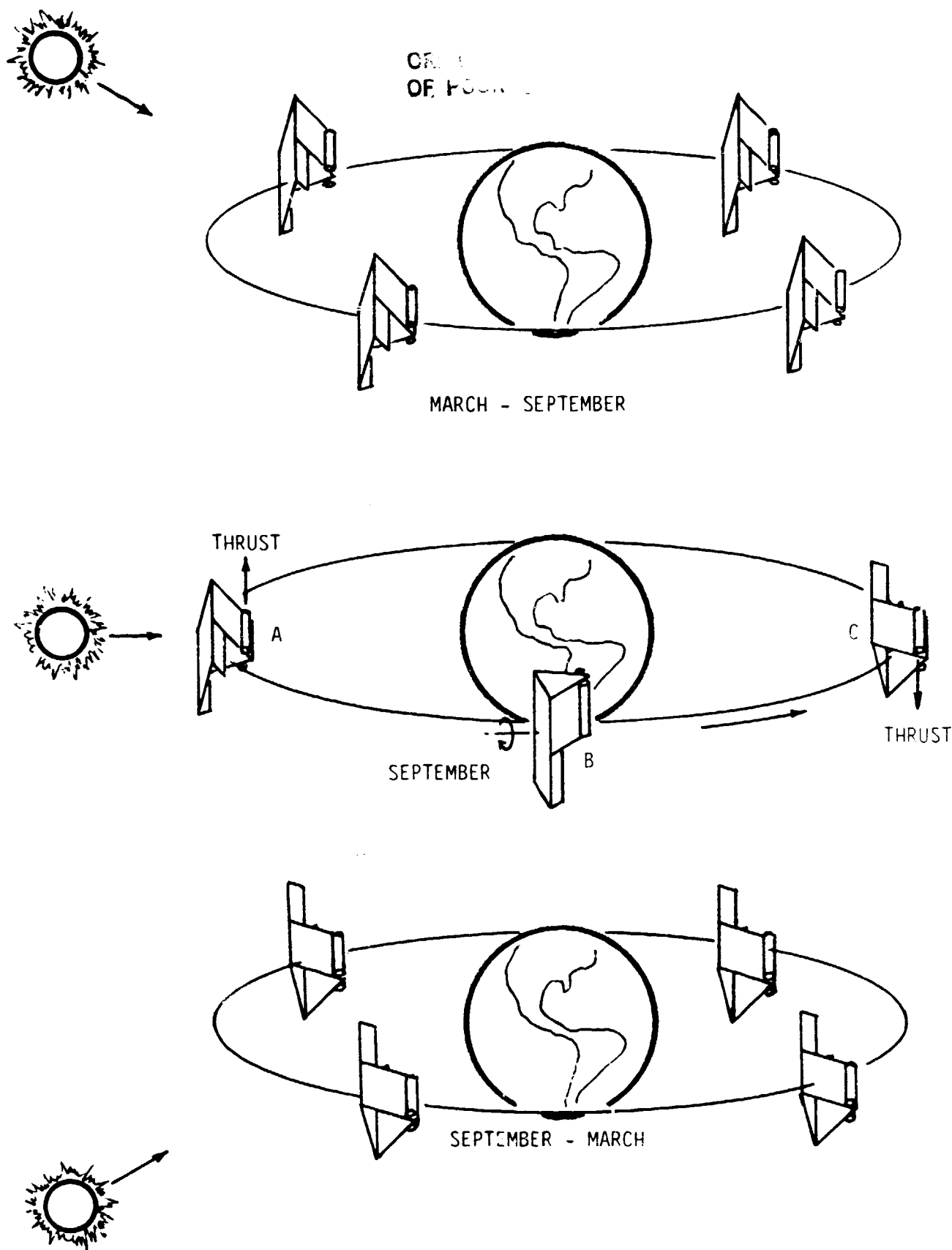


Figure 2.3-3. Delta Orientation

transfer ellipse for orbit makeup. This maneuver may be done in increments over several orbits. After completing this maneuver, the station is rotated 180° about the Z axis (B) and a second posigrade maneuver at C circularizes the orbit at the required altitude. In March, the procedure is repeated. In this way, orbit decay is made up every six months, and thrusters are needed at only one location on the station. Contamination-sensitive sensors can thus be located far from the exhaust plume.

2.3.3 Elements

The delta comprises a number of pressurized and unpressurized modular elements, arranged as shown in figures 2.3-1 and 2.3-2.

2.3.3.1 Command/Control Module (C/CM)

The C/CM is the primary command and operations work station. It also provides crew support in the event of functional loss of the habitation module in the IOC phase. The C/CM is arranged as illustrated in figure 2.3-4. Berthing mechanisms are installed at both ends. Overall length between berthing interfaces is 264", partly to provide volume for avionics and contingency crew accommodation and partly to maintain a standard module length for assembly versatility. One C/CM is required at IOC; a second C/CM is added in the growth station.

2.3.3.2 Habitation Module (HM)

The HM (figure 2.3-5) is the primary location for all crew support functions, including food, hygiene, waste management, health maintenance, sleep, and recreation for a crew of eight. A minimal command station provides backup capability in case the C/CM becomes unusable. Overall length between berthing

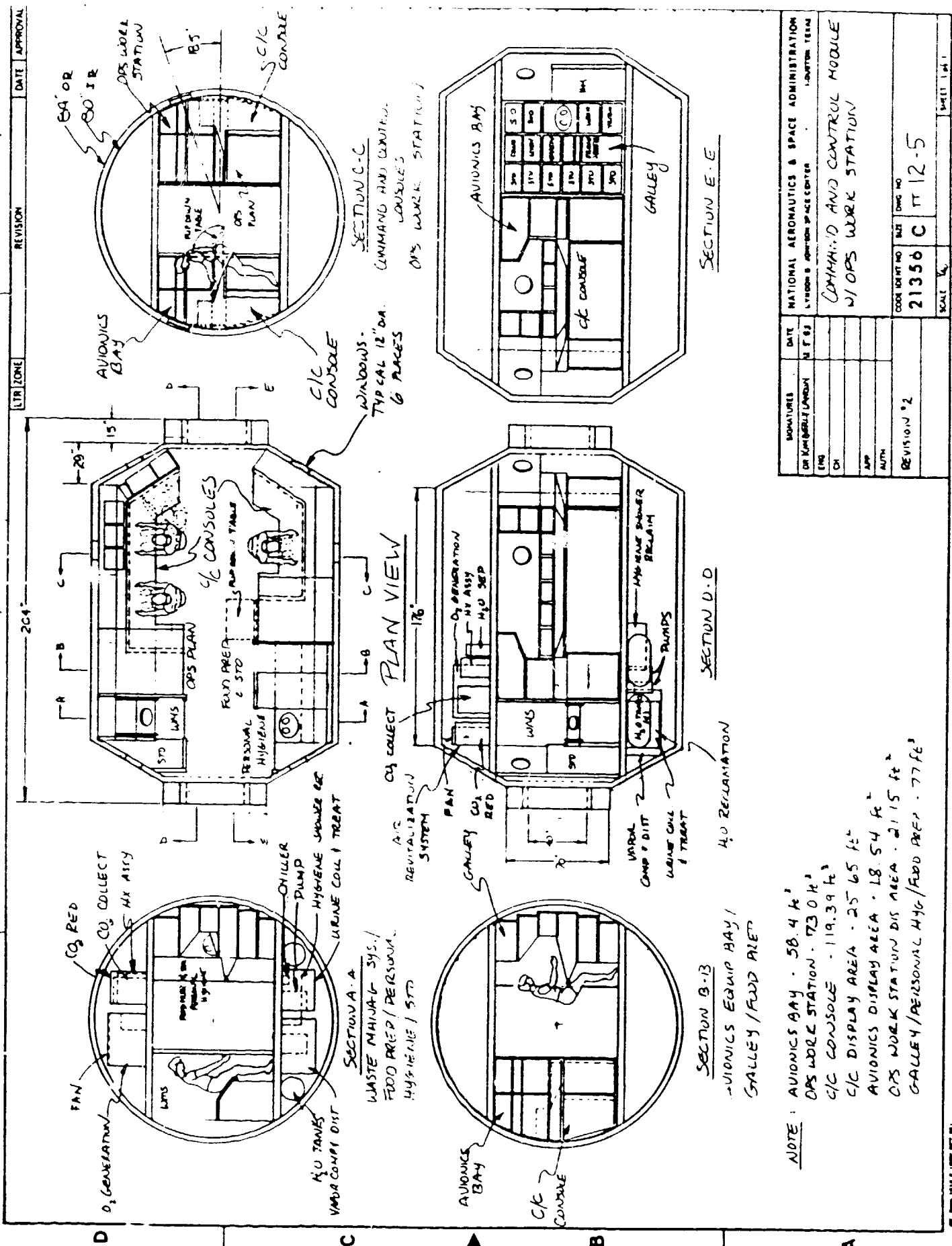
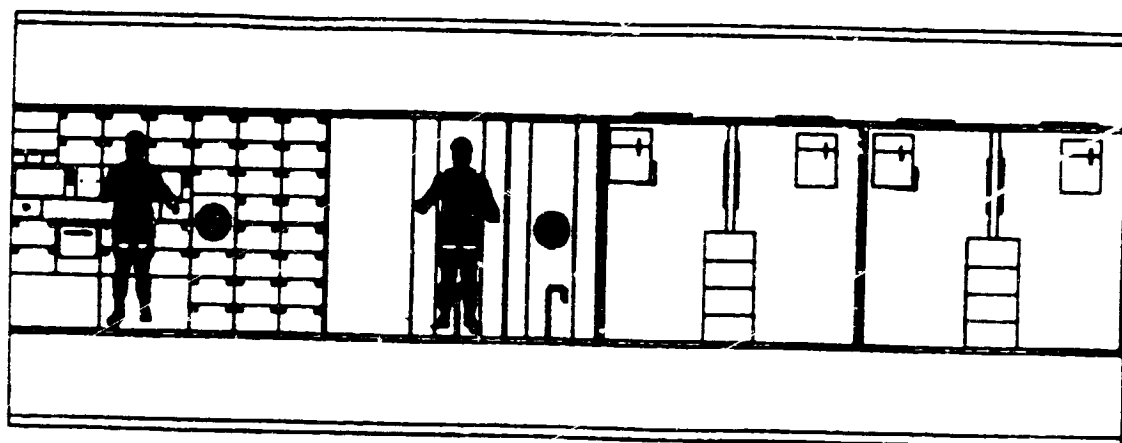
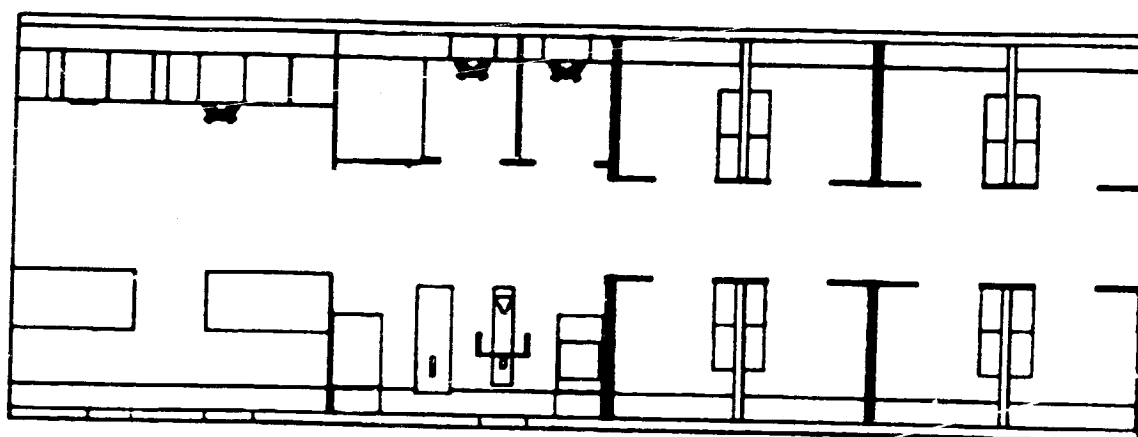


Figure 2.3-4b

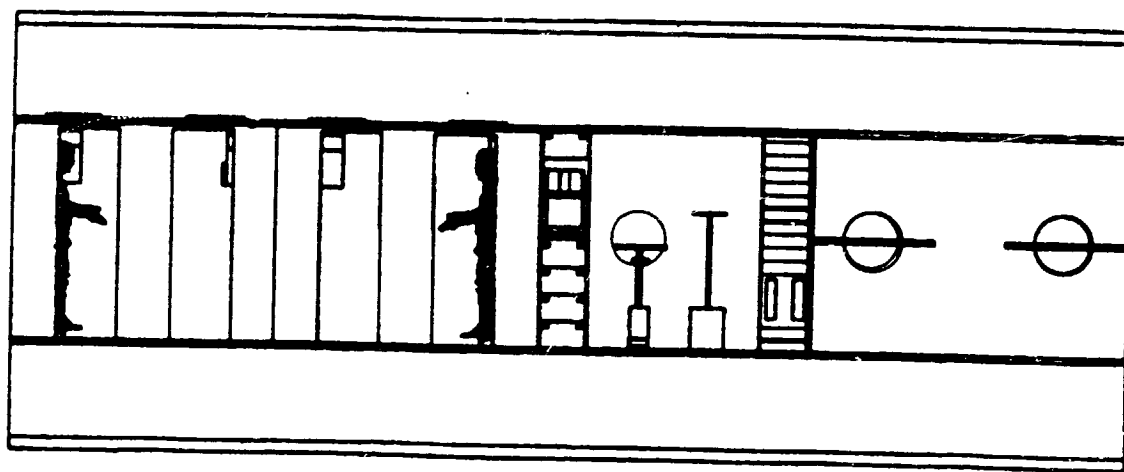


LEFT SIDE VIEW

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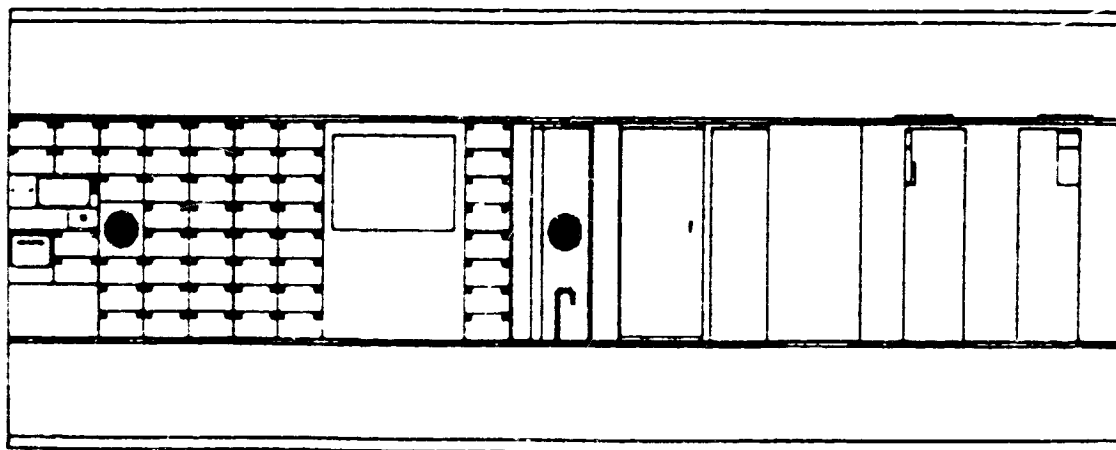


PLAN VIEW



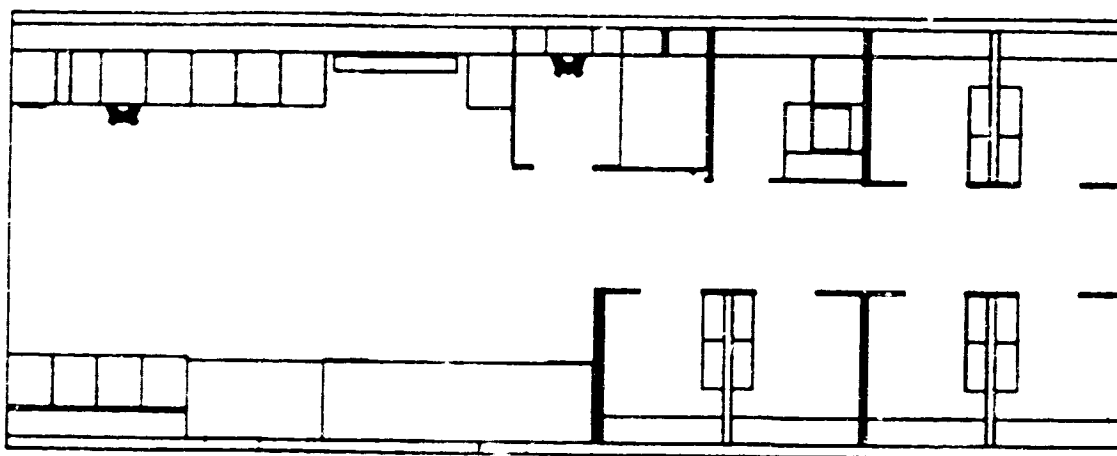
RIGHT SIDE VIEW

Figure 2.3-5a. Habitation Module 1

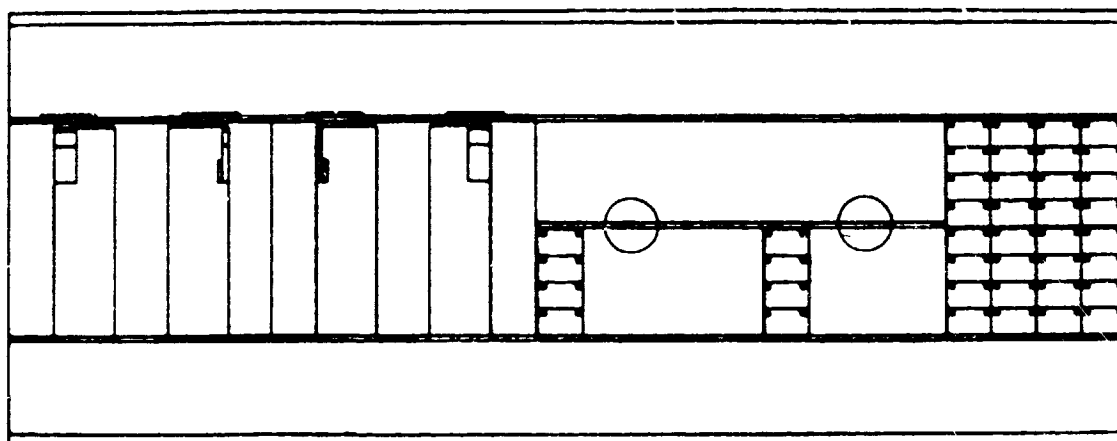


LEFT SIDE VIEW

SECTION
OF ROOM 2



PLAN VIEW



RIGHT SIDE VIEW

Figure 2.3-5b. Habitation Module 2

interfaces is 528", or twice that of the C/CM. The IOC station includes one HM and the growth station two.

2.3.3.3 Laboratory Module (LM)

The LM provides a pressurized facility for scientific, developmental and production activities on the station. It includes interfaces with station utilities such as electrical power, thermal control, data management, communications and life support. It also provides structural mounting for interior user equipment. It is built in two sizes which are structurally identical to the C/CM and HM respectively. This permits a late choice between the adaptability of smaller modules and the structural efficiency and internal volume of the larger module because two short LM's can be replaced in the configuration by one long LM or vice versa. Two short LM's are provided in the IOC station. Two short LM's and one long LM are added in the growth phase.

2.3.3.4 Interconnect Module (IM)

The IM (figure 2.3-6) serves primarily as a means of connecting station elements at right angles without wasting valuable volume in the 14 ft. diameter modules for side ports. The IM has five berthing ports that can be fitted to accommodate the Shuttle Orbiter or connect pressurized station modules, manipulators, and other station elements. It can also be equipped as an airlock for two crewmen. Four IM's are required on the IOC station and four more on the growth version.

2.3.3.5 Logistics Module

The logistics module serves as a carrier for supplies and equipment brought from earth and for products and waste material to be returned. It is

structurally similar to the C/CM with a single berthing port on one end and a rack for tanks and other external stores on the other end.

2.3.3.6 Electrical Power Unit

The electrical power generation subsystem is built in modular form to facilitate installation. Each unit consists of solar array packages, energy storage and conversion units, and a dedicated thermal control subsystem capable of supplying 25 KW of electrical power continuously. Three units are included in the IOC configuration and six in the growth configuration.

2.3.3.7 Tunnel

An 80" diameter tunnel is used to provide a closed loop of pressurized modules at IOC. A second tunnel is added in the growth phase to enhance internal traffic flow.

2.3.3.8 Truss

A deployable tetrahedral planar truss is used as a structural foundation for the station. It provides mounting for pressurized modules, external subsystems, support service facilities, and payloads.

2.3.3.9 Manipulator

An Orbiter-type RMS mounted on a standard berthing mechanism, which can be truss or module attached and controlled remotely from the C/CM, is used to transport massive items from place to place on the station and to assist the Orbiter RMS in station assembly and resupply.

One RMS is provided at IOC and three in the growth phase.

2.3.3.10 Vehicle Support Facilities

Vehicle support facilities include unpressurized hangars for servicing and protected storage, propellant storage and transfer facilities, and equipment

and spares for checkout and maintenance. The IOC capability includes provisions for one OMV. In the growth station, two OMV's and two OTV's can be accommodated.

2.3.4 Subsystem Distribution

The table below summarizes the location of subsystem components within the station.

SUBSYSTEM COMPONENT LOCATION SUMMARY

	C/CM	HM	LM	LOG.	IM	TRUSS
ECLSS	X	X	X	/	-	-
THERMAL CONTROL	X	X	X	X	/	X
PROPULSION/RCS	X	-	-	-	-	-
COMM/TRACKING	X	/	/	/	/	X
DATA MANAGEMENT	x	(X)	/	/	/	/
ELECTRICAL POWER	/	/	/	/	/	X
MECHANISMS	X	X	X	X	X	X
CREW ACCOMMODATIONS	(X)	X	/	/	/	-
GNC	X	(X)	-	-	-	-

- X PRIMARY LOCATION OF MAJOR COMPONENTS
- (X) BACKUP LOCATION OF MAJOR COMPONENTS
- / LOCATION OF SOME MINOR COMPONENTS
- NO SUBSYSTEM COMPONENTS

2.3.5 Mass Properties

The estimated mass properties of the Delta configuration are summarized in the following table. Element weights include associated subsystems. Although these estimates do not include an allowance for weight growth, some growth can be expected to occur. This would increase the weights and inertias given, but would not appreciably alter the relative magnitudes of the inertias. See figure 2.3-2 for coordinate system definition.

DELTA			
	UNIT MASS LB.	IOC	QUANTITY GROWTH
C/CM	27,700	1	2
HM	51,300	1	2
SINGLE LM	27,700	2	4
DOUBLE LM	51,300	-	1
IM	10,000	4	8
TUNNEL	1,090	1	2
LOGISTICS	27,700	1	1
POWER SYSTEM	5,590	3	6
TRUSS - IOC	10,110	1	-
GROWTH	15,340	-	1
MANIPULATOR	2,000	1	3
OMV HANGAR	4,320	1	1
OTV HANGAR	8,520	-	1
OTV PROP. TANK	6,600	-	1
SATELLITE SVC. STR.	2,080	1	2

		IOC	GROWTH	
			W/O OTV PROP.	W/OTV PROP.
MASS, LB		238,470	508,460	634,460
C.G., IN.	X	1,165.8	1,679.8	1,723.9
	Y	-62.8	-46.1	-36.9
	Z	573.1	554.7	565.7
I_{xx} , 10^6 SLUG-FT ²		13.574	27.370	27.563
I_{yy}		14.090	59.301	60.977
I_{zz}		8.577	48.167	49.822
I_{xy}		-0.915	-1.407	-1.184
I_{xz}		3.029	7.682	7.949
I_{yz}		-2.185	-4.436	-4.381

2.3.6 Cost Overview Delta Configuration

The cost for the Delta configuration is \$8 billion in 1984 at IOC. The groundrules and assumptions upon which this cost estimate is made is discussed in section 3.3.6.1. The cost is virtually the same as the BB configuration. Therefore, the differences in the concepts were offsetting in terms of costs for all practical purposes. The costs of the truss and tunnel elements (additive for this alternative) were offset by the deletion of the solar boom equipment, one C/C module, and the satellite support system.

Figures 2.3.6-1 and 2.3.6-2 present the breakout of the \$8 billion for the DDT&E phase and production phase, respectively. It is immediately evident that the majority cost of the program is in "overhead" costs, such as system level and program level tasks. Approximately 75% of the DDT&E cost are in this category, contrasted to approximately 25% for hardware development. Roughly 40% of the production costs are system and program level costs, leaving approximately 60% for actual hardware production.

FIG. 2.3.6-1

DELTA CONFIGURATION
DDTE COST SUMMARY BY MODULE

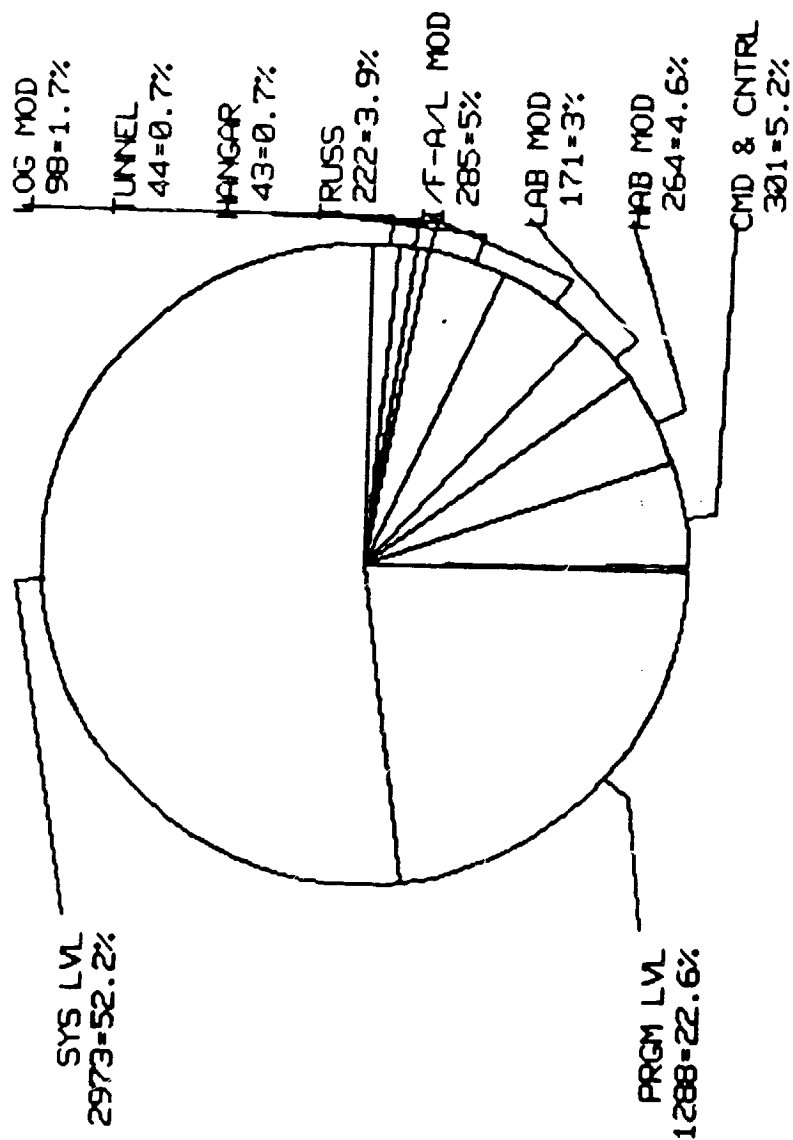
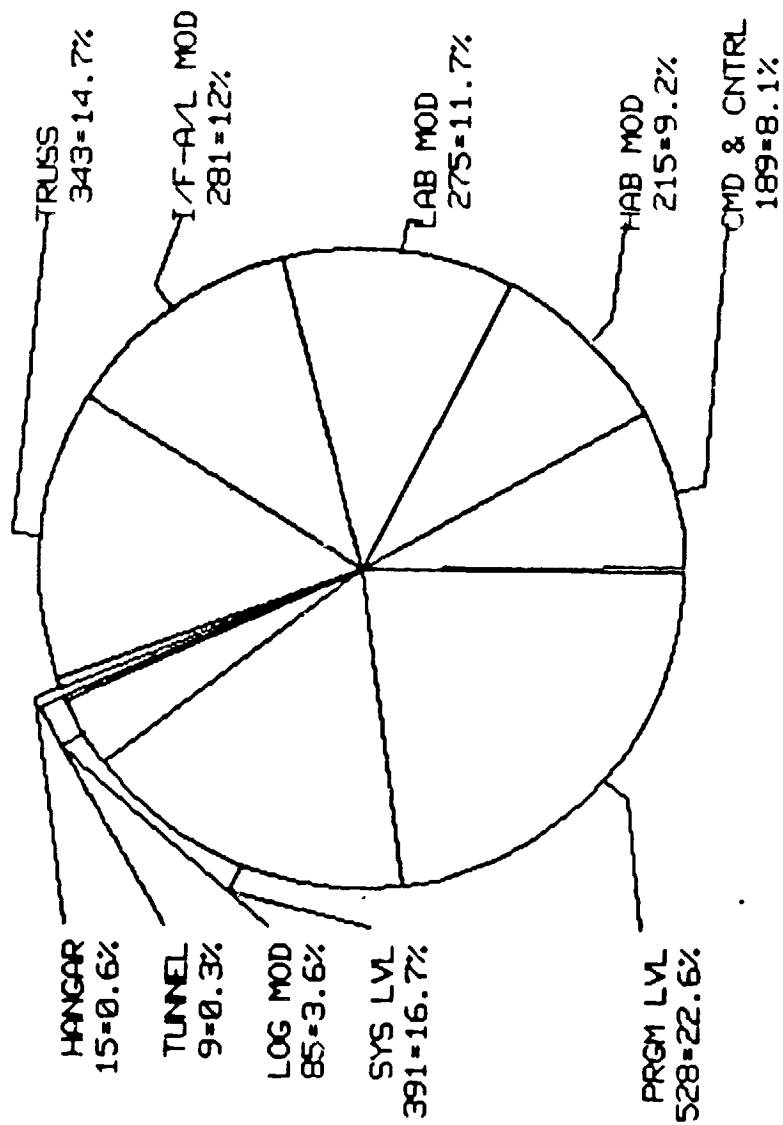


FIG. 2.3.6-2

DELTA CONFIGURATION
PROD COST SUMMARY BY MODULE



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2.4 Big "T" Configuration

2.4.1 General Arrangement

The "T" concept clusters the pressurized modules and most operational support facilities at the lower end of a vertical planar truss. Solar arrays, antennas and astronomical sensors are mounted on a horizontal planar truss at the upper end of the vertical truss. The IOC configuration, shown in figure 2.4-1, includes the complete vertical truss and half of the solar array truss. The pressurized modules are grouped at one corner in a quadrangular arrangement.

In the growth configuration, the other half of the array truss is added at the top of the vertical truss. The additional pressurized modules fill the bottom edge of the vertical truss.

Hangars and other operational support facilities are mounted above the pressurized modules, as are the thermal control system radiators. Radiators for the electrical power system are located under the solar array truss.

2.4.2 Function/Operation

The "T" configuration is maintained in an earth-fixed attitude with the two trusses parallel to the velocity vector (figure 2.4-3). This orientation minimizes drag and is gravity gradient stable.

The solar array truss is rotated about the velocity vector up to 17° from the horizontal to maintain at least nominal power output as Beta varies up to 52° (see figure 2.4-4).

Several Orbiter berthing ports are available. These and others are also available for installation of temporary modules and payloads. Space is also available on the truss for unpressurized payload attachment.

Orbit makeup is accomplished by thrusters mounted on the IOC C/C module.

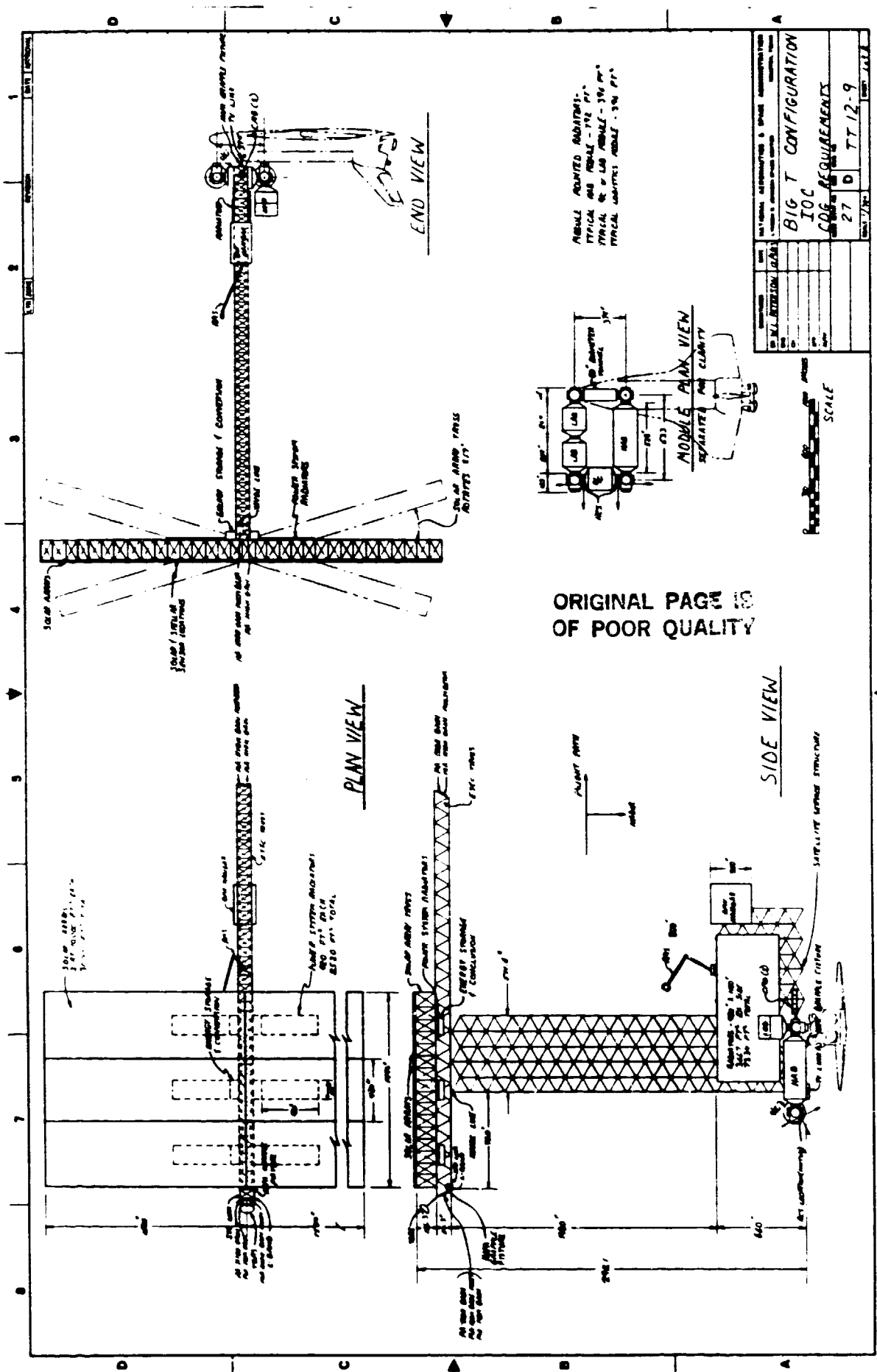


Figure 2.4-1a

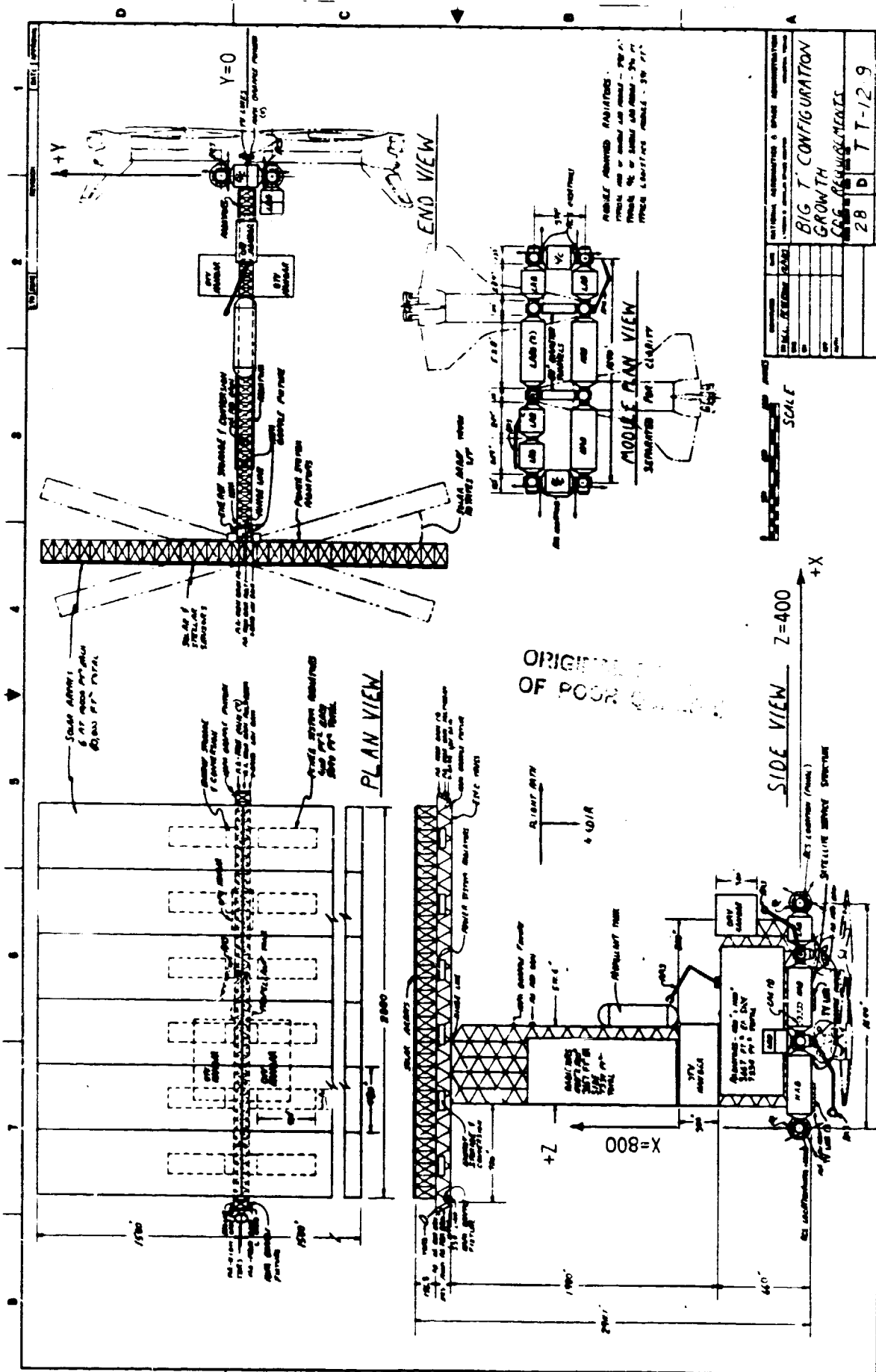


Figure 2.4-2a

BIG "T" IOC

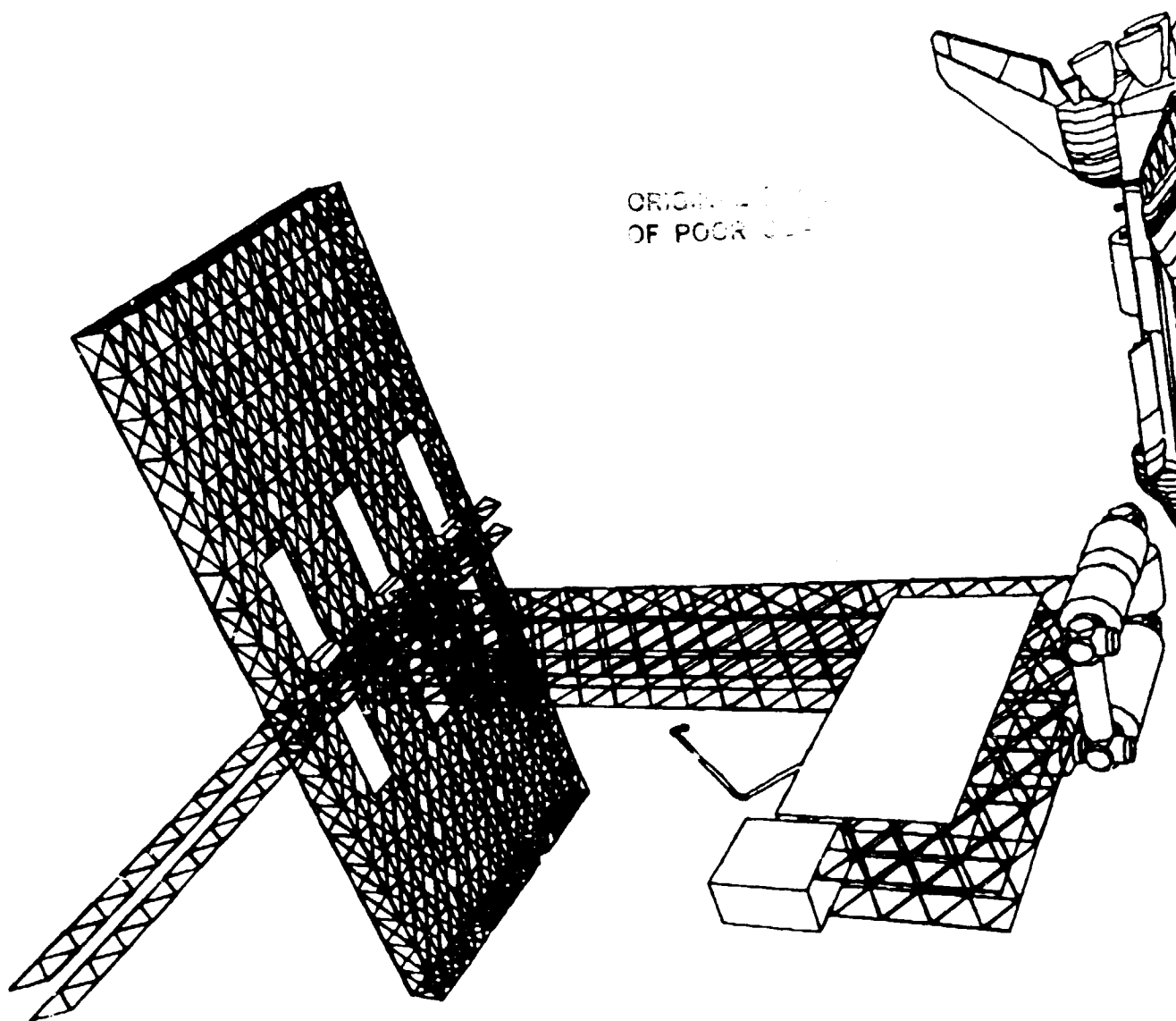


Figure 2.4-1b

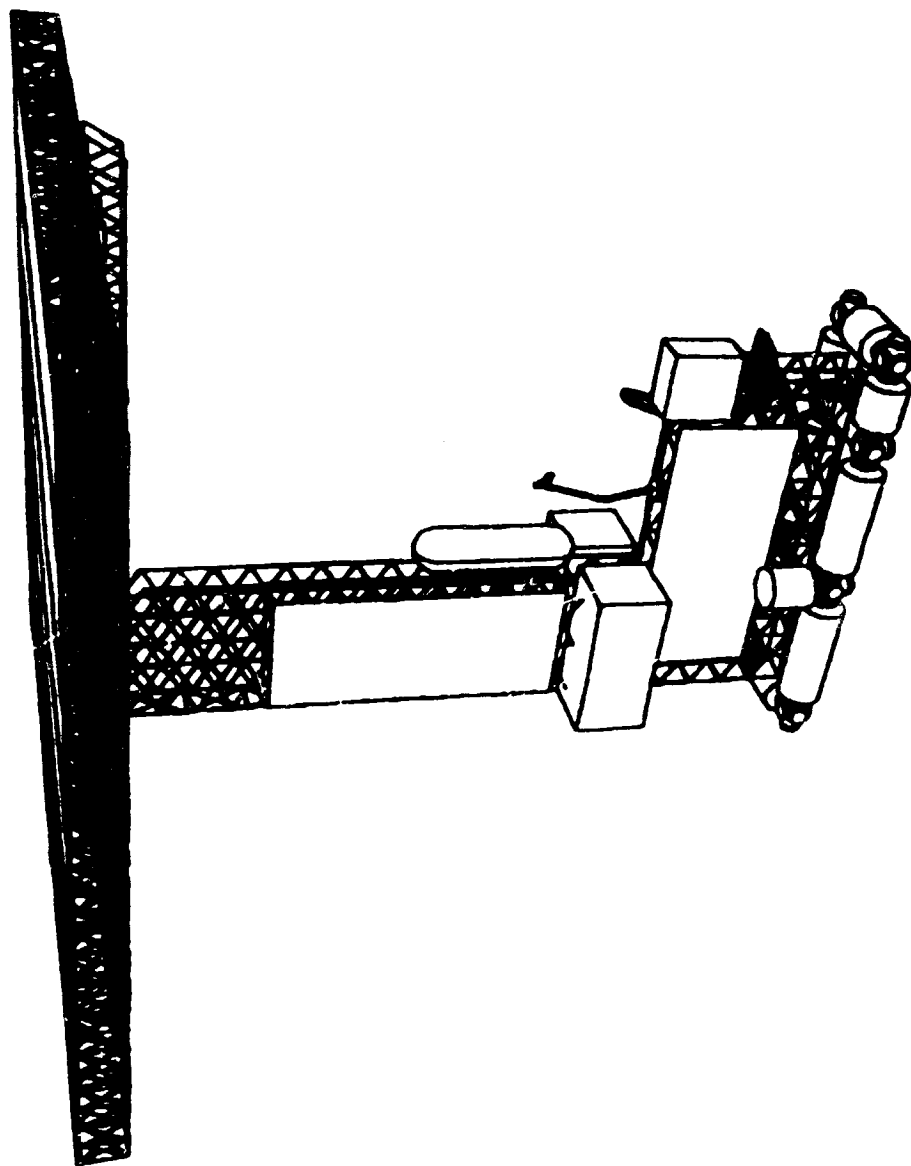


Figure 2.4-2b Big "T" Growth Configuration

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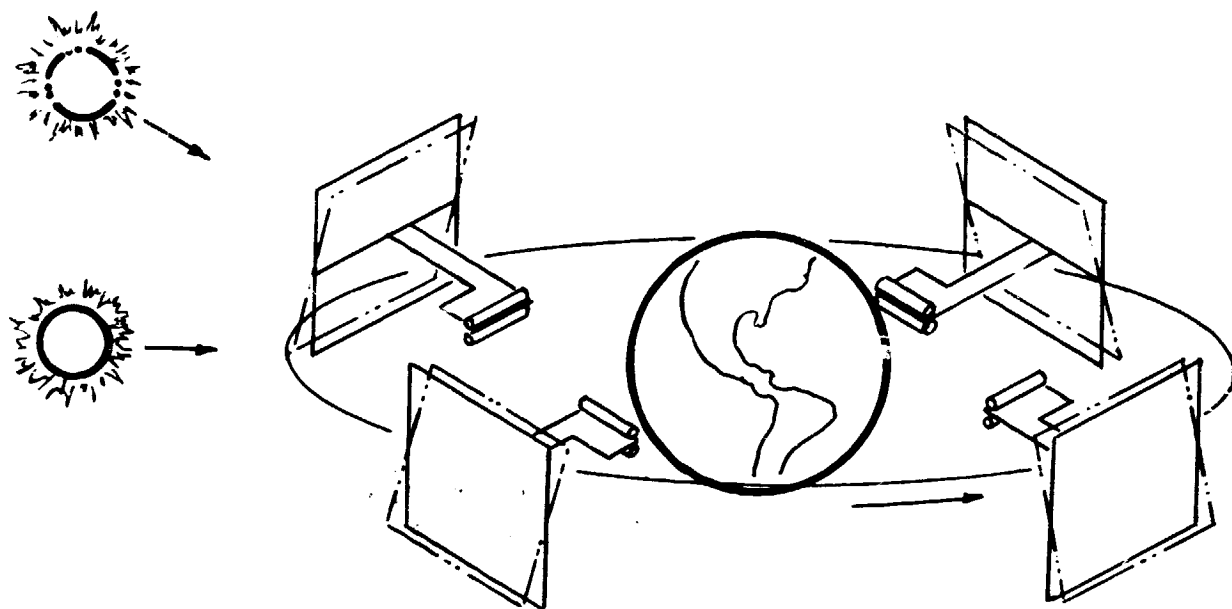


Figure 2.4-3. Tee Orientation

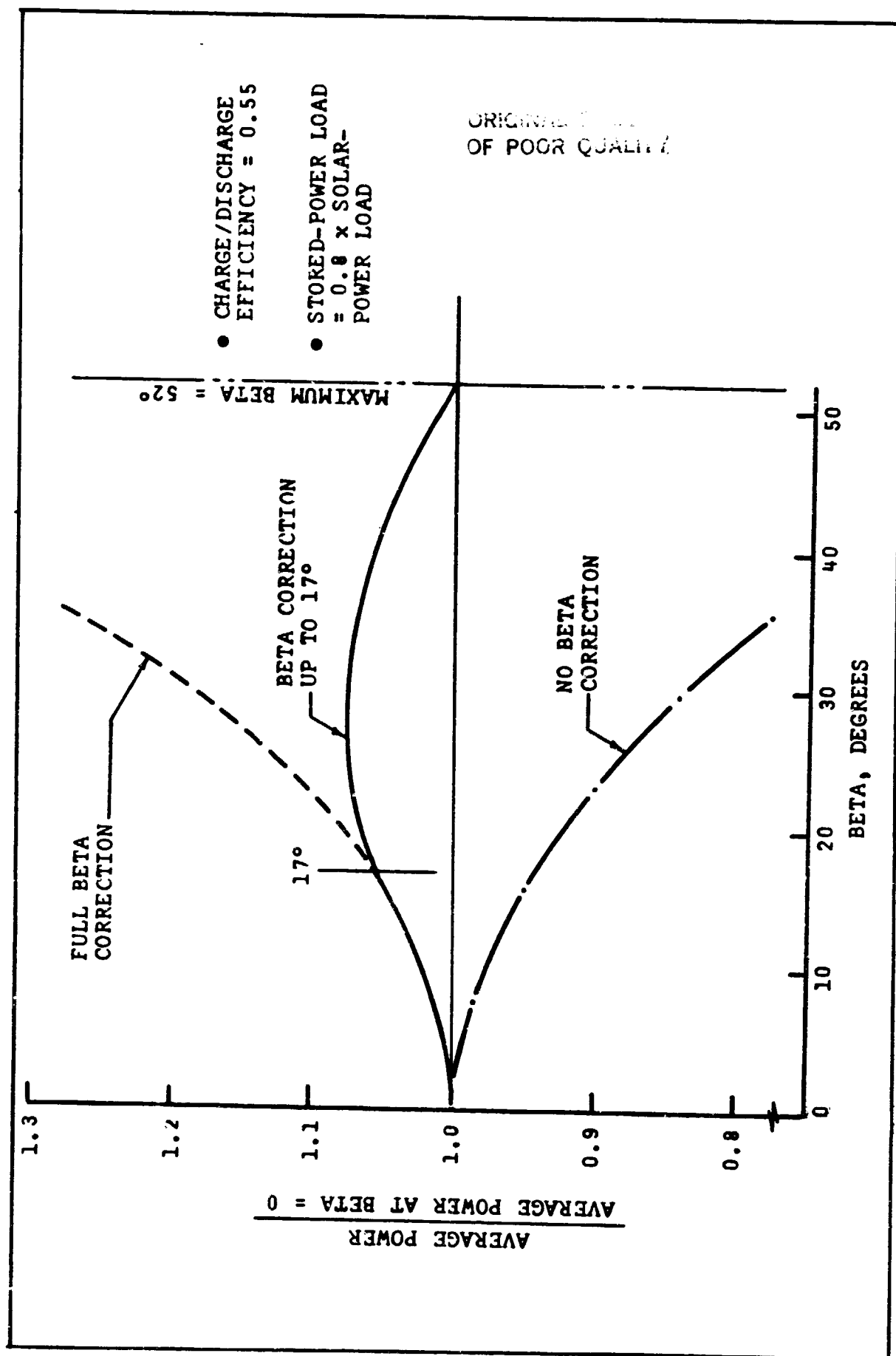


Figure 2.4-4. Electrical Power - Big "T"

Contamination-sensitive instruments can therefore be mounted on the forward edge of the array truss for a good view factor and optimum environment. Earth sensors can be located in the pressurized modules if desired for calibration purposes.

2.4.3 Elements

The "T" concept comprises a number of pressurized and unpressurized modular elements, arranged as shown in figures 2.4-1 and 2.4-2.

2.4.3.1 Command/Control Module (C/CM)

The C/CM is the primary command and operations work station. It also provides crew support in the event of functional loss of the habitation module in the ICC phase. The C/CM is arranged as illustrated in figure 2.4-5. Berthing mechanisms are installed at both ends. Overall length between berthing interfaces is 264", partly to provide volume for avionics and contingency crew accommodation and partly to maintain a standard module length for assembly versatility. One C/CM is required at IOC; a second C/CM is added in the growth station.

2.4.3.2 Habitation Module (HM)

The HM (figure 2.4-6) is the primary location for all crew support functions, including food, hygiene, waste management, health maintenance, sleep, and recreation for a crew of eight. A minimal command station provides backup capability in case the C/CM becomes unusable. Overall length between berthing interfaces is 528", or twice that of the C/CM. The IOC station includes one HM and the growth station two.

2.4.3.3 Laboratory Module (LM)

The LM provides a pressurized facility for scientific, developmental and

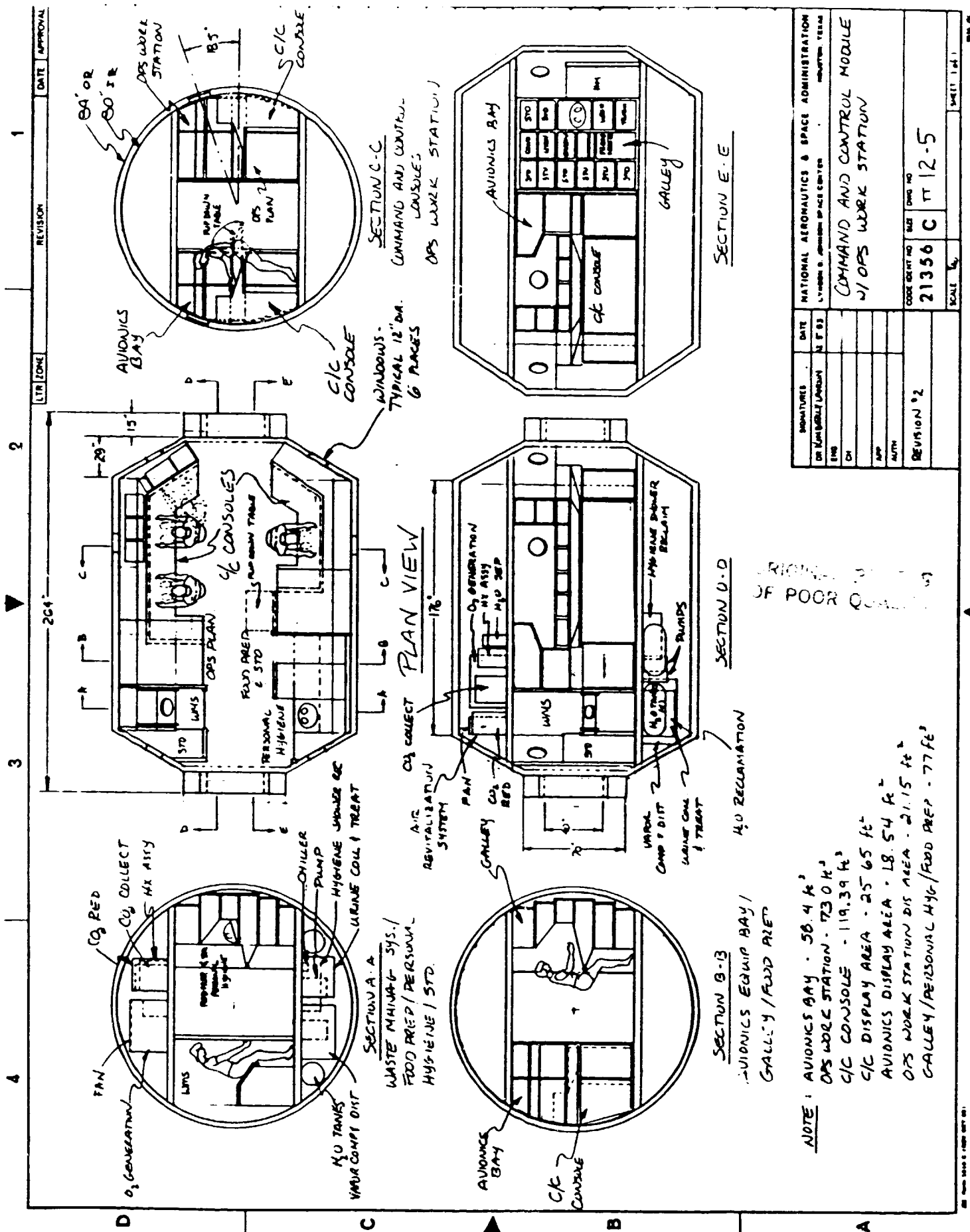
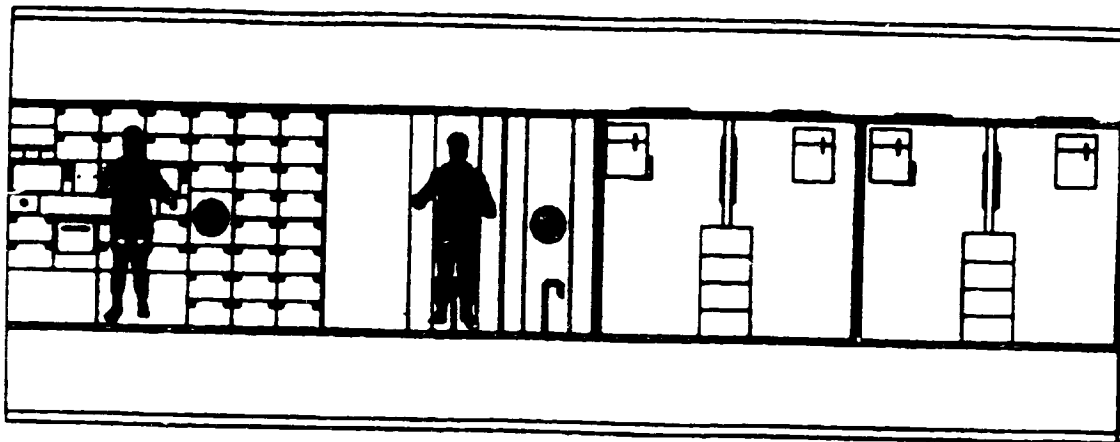
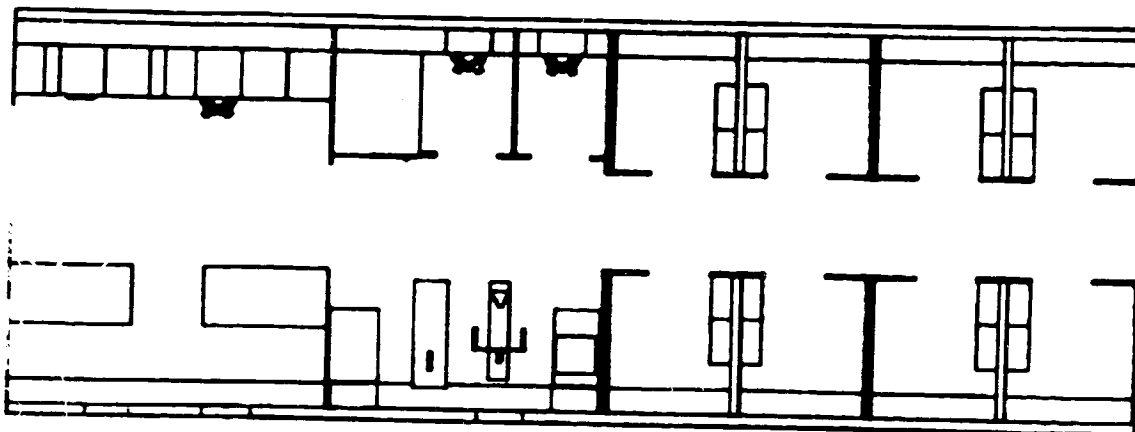


Figure 2.4-5b

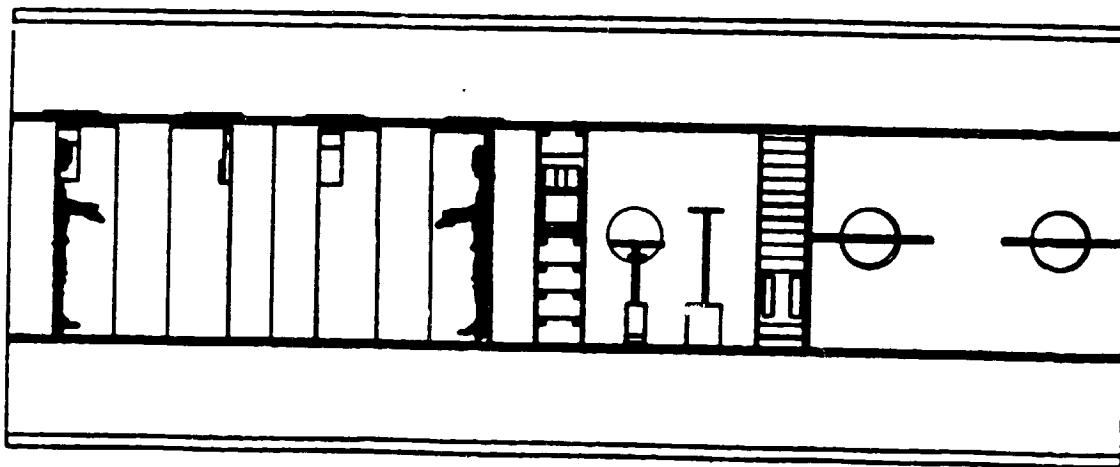
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LEFT SIDE VIEW

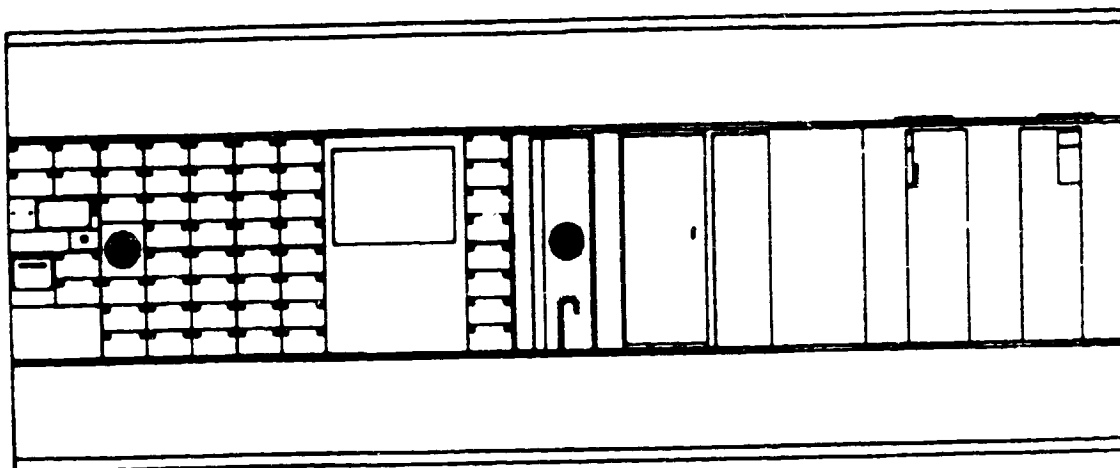


PLAN VIEW



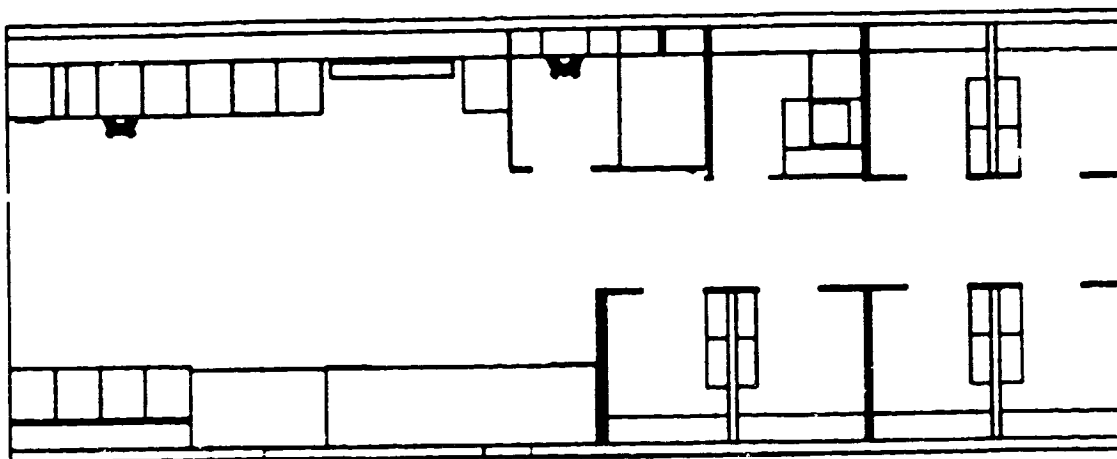
RIGHT SIDE VIEW

Figure 2.4-6a. Habitation Module 1

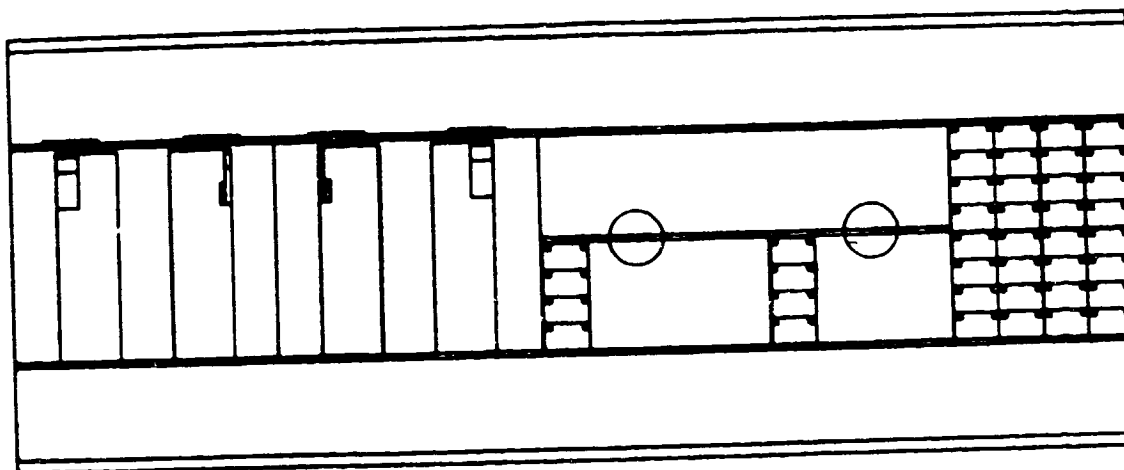


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PLAN VIEW



RIGHT SIDE VIEW

Figure 2.4-6b. Habitation Module 2

production activities on the station. It includes interfaces with station utilities such as electrical power, thermal control, data management, communications and life support. It also provides structural mounting for interior user equipment. It is built in two sizes which are structurally identical to the C/CM and HM respectively. This permits a late choice between the adaptability of smaller modules and the structural efficiency and internal volume of the larger module because two short LM's can be replaced in the configuration by one long LM or vice versa. Two short LM's are provided in the IOC station. Four short LM's and one long LM are added in the growth phase.

2.4.3.4 Interconnect Module (IM)

The IM (figure 2.4-7) serves primarily as a means of connecting station elements at right angles without wasting valuable volume in the 14 ft. diameter modules for side ports. The IM has six orthogonal berthing ports that can be fitted to accommodate the Shuttle Orbiter or connect pressurized station modules, manipulators, and other station elements. It can also be equipped as an airlock for two crewmen. Four IM's are required on the IOC station and four more on the growth version.

2.4.3.5 Logistics Module

The logistics module serves as a carrier for supplies and equipment brought from earth and for products and waste material to be returned. It is structurally similar to the C/CM with a single berthing port on one end and a rack for tanks and other external stores on the other end.

2.4.3.6 Electrical Power Unit

The electrical power generation subsystem is built in modular form to facilitate installation. Each unit consists of solar array packages, energy

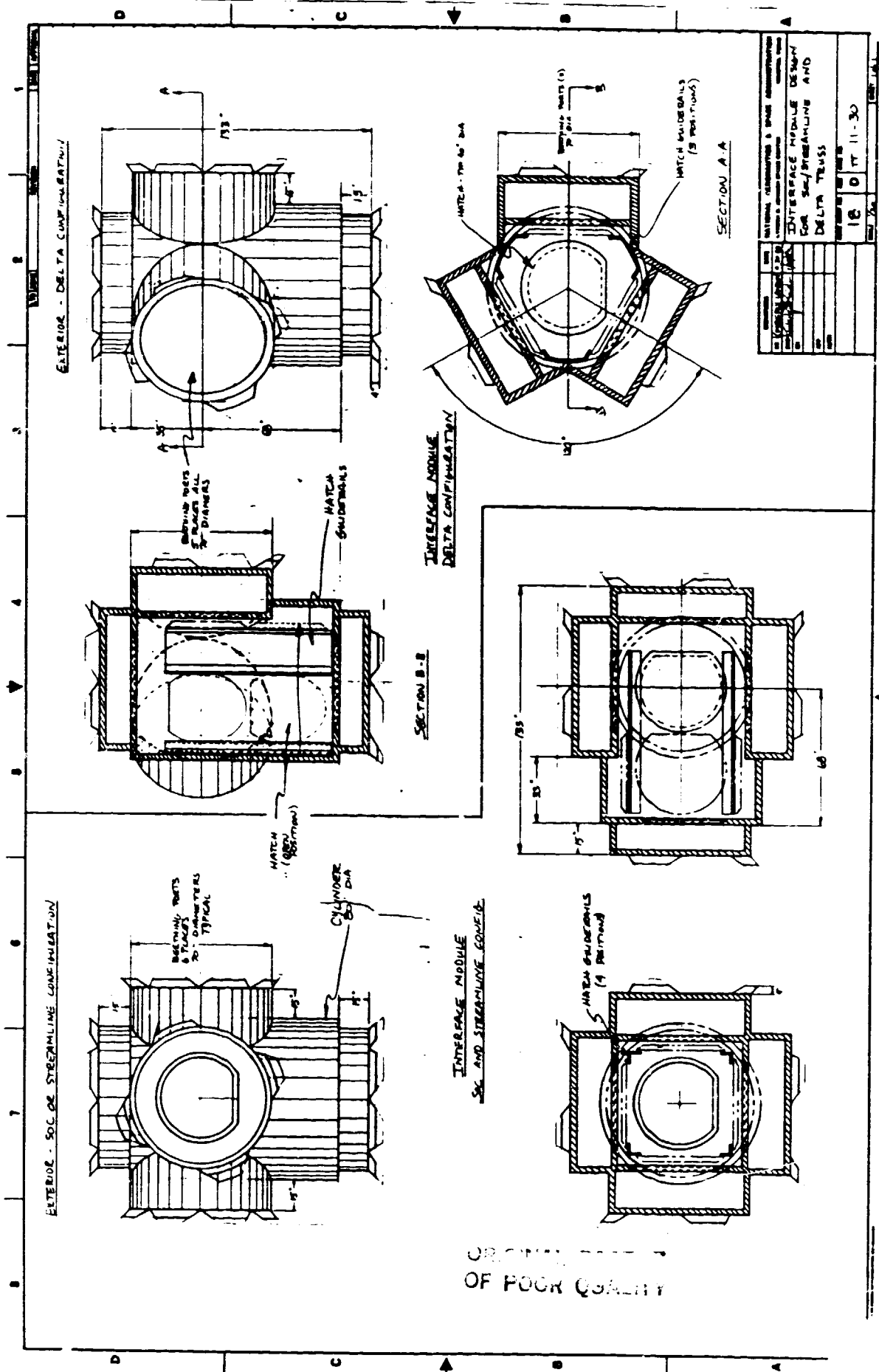


Figure 2.4-7

storage and conversion units, and a dedicated thermal control subsystem capable of supplying 25 KW of electrical power continuously. Three units are included in the IOC configuration and six in the growth configuration.

2.4.3.7 Tunnel

Tunnels 80" in diameter are used to provide additional egress paths from the pressurized modules prior to full growth buildup and to improve internal traffic flow. One tunnel is installed at IOC and a second during the growth phase.

2.4.3.8 Truss

Deployable tetrahedral planar trusses form the structural framework of the station. They provide mounting for pressurized modules, external subsystems, support and service facilities and payloads. The entire truss is emplaced during IOC buildup except for half of the solar array truss.

2.4.3.9 Manipulator

An Orbiter-type RMS mounted on a standard berthing mechanism, which can be truss or module attached, and controlled remotely from the C/CM is used to transport massive items from place to place on the station and to assist the Orbiter RMS in station assembly and resupply.

One RMS is provided at IOC and three in the growth phase.

2.4.3.10 Vehicle Support Facilities

Vehicle support facilities include unpressurized hangars for servicing and protected storage, propellant storage and transfer facilities, and equipment and spares for checkout and maintenance. The IOC capability includes provisions for one OMV. In the growth station, two OMV's and two OTV's can be accommodated.

2.4.4 Subsystem Distribution

The table below summarizes the location of subsystem components within the station.

SUBSYSTEM COMPONENT LOCATION SUMMARY

	C/CM	HM	LM	LOG.	IM	TRUSS
ECLSS	X	X	X	/	-	-
THERMAL CONTROL	X	X	X	X	/	X
PROPULSION/RCS	X	-	-	-	-	-
COMM/TRACKING	X	/	/	/	/	X
DATA MANAGEMENT	x	(X)	/	/	/	/
ELECTRICAL POWER	/	/	/	/	/	X
MECHANISMS	X	X	X	X	X	X
CREW ACCOMMODATIONS	(X)	X	/	/	/	-
GNC	X	(X)	-	-	-	-

X PRIMARY LOCATION OF MAJOR COMPONENTS

(X) BACKUP LOCATION OF MAJOR COMPONENTS

/ LOCATION OF SOME MINOR COMPONENTS

- NO SUBSYSTEM COMPONENTS

2.4.5 Mass Properties

The estimated mass properties of the "T" configuration are summarized in the following table. Element weights include associated subsystems. Although these estimates do not include an allowance for weight growth, some growth can be expected to occur. This would increase the weights and inertias given, but would not appreciably alter the relative magnitudes of the inertias. See figure 2.4-2 for coordinate system definition.

"T"

	UNIT MASS LB.	IOC	QUANTITY GROWTH
C/CM	27,700	1	2
HM	51,300	1	2
SINGLE LM	27,700	2	4
DOUBLE LM	51,300	-	1
IM	11,300	4	8
TUNNEL	1,090	1	2
LOGISTICS	27,700	1	1
POWER SYSTEM	11,010	3	6
TRUSS - IOC	8,770	1	-
GROWTH	14,320	-	1
MANIPULATOR	2,000	1	3
OMV HANGAR	3,600	1	1
OTV HANGAR	7,100	-	2
OTV PROP. TANK	6,600	-	1
SATELLITE SVC. STR.	2,080	1	2

	IOC	GROWTH W/O OTV PROP.	W/OTV PROP.
MASS, LB.	257,870	555,320	681,320
C.G., IN. X	1,147.9	1,608.1	1,605.7
Y	-17.1	-7.9	-6.5
Z	769.3	772.2	893.2
$I_{xx}, 10^6 \text{ SLUG-FT}^2$	46.006	96.768	106.672
I_{yy}	47.824	126.427	136.334
I_{zz}	9.649	46.160	46.246
I_{xy}	-0.324	0.063	0.060
I_{xz}	-1.167	0.736	0.545
I_{yz}	0.139	0.133	0.249

2.4.6 Cost Overview - Big "T" Configuration

The big "T" configuration has been costed at \$8.7 billion in 1984 at IOC. This is the most costly of the three alternative configurations. This is primarily due to the additional truss structure, additional solar array requirements, and more fuel cells. However, as a comparison of the costs for all three configurations would indicated, the difference is relatively small (less than 10%).

Figures 2.4.6-1 and 2.4.6-2 present the breakout of the \$8.7 billion for the DD&TE phase and production phase, respectively. It is immediately evident that the majority of the cost of the program is in "overhead" costs, such as system level and program level tasks. Approximately 75% of the DDT&E costs are in this category, contrasted to approximately 25% for hardware development. Roughly 40% of the production costs are system and program level costs, leaving approximately 60% for actual hardware production.

FIG. 2.4.6-1

BIG T CONFIGURATION
DDTE COST SUMMARY BY MODULE

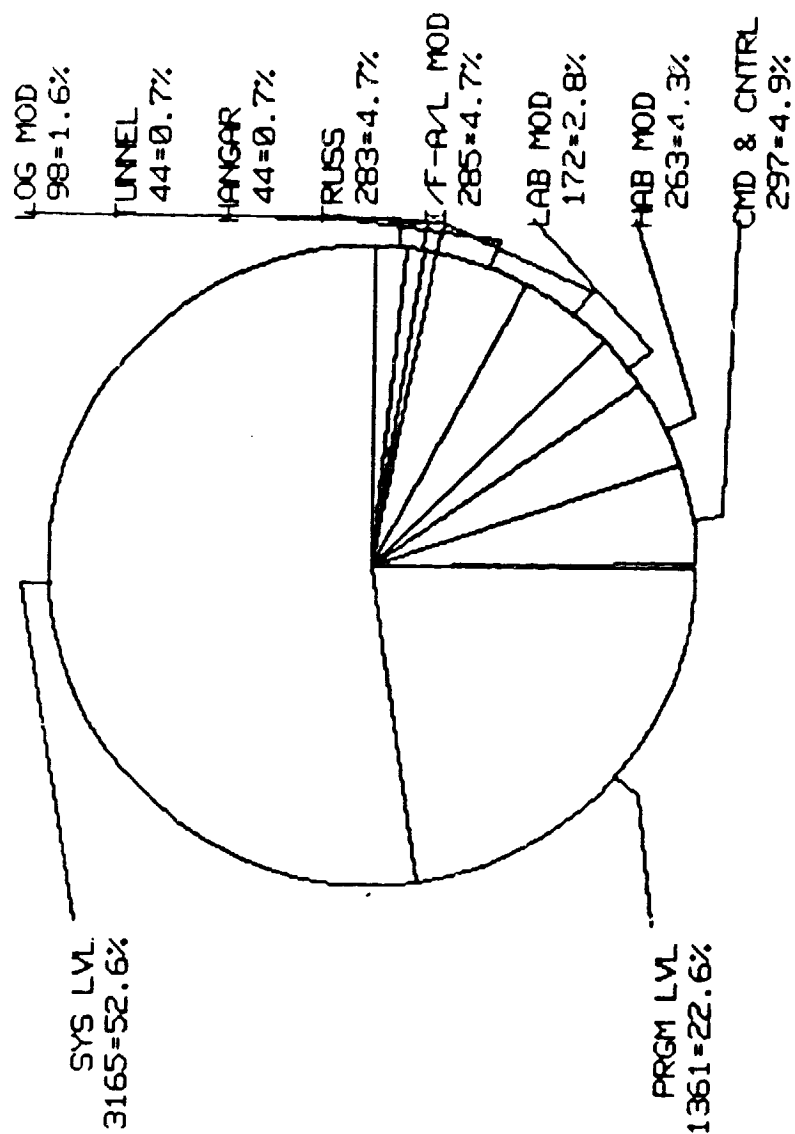
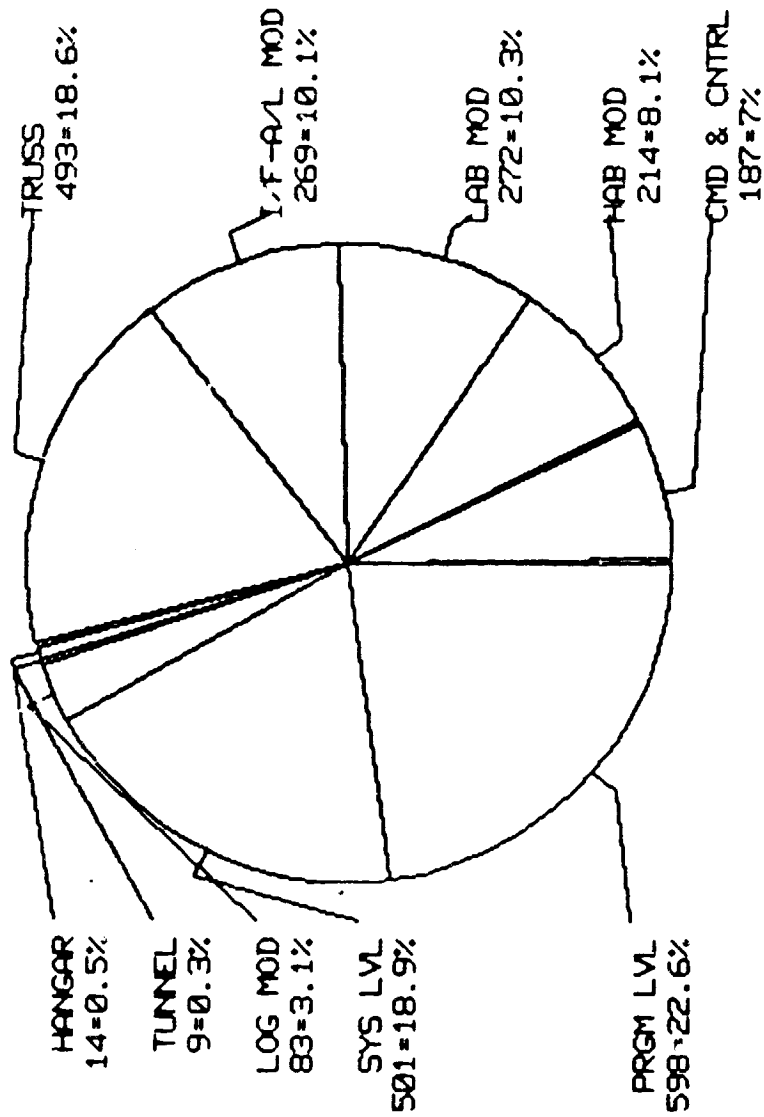


FIG. 2.4.6-2

BIG T CONFIGURATION
PROD COST SUMMARY BY MODULE



3.0 CONCEPT FUNCTIONS DESCRIPTION AND EVALUATION

3.1 Introduction

In this study, the desirable features or evaluation criteria will be identified and discussed, the means used to meet the requirements, and criteria described and judgments supported by qualitative and quantitative data (when possible) will be made.

The criteria or desirable features were defined in terms of user accommodations, system engineering, operations, safety, programmic features, and technology availability. In concert with the CDG's work on the subject, the criteria in the user accommodation and system engineering areas were subdivided into view factors, access and clearance, arrangement versatility, dynamics and control, and assembly and growth. An attempt was made to include not only the basis for quantifying the configuration's performance or required functions such as orbit maintenance and attitude control, but also for evaluating those features which may be desirable such as compatibility with tethers for science.

Except as dictated by configuration differences, the same basic subsystem concepts were applied to all three Space Station configurations. This practice extended to the size, interior provisions, and arrangements of pressurized modules, such that differences in costs, performance, and crew and user evaluations should be dependent primarily in the differences in the configuration concepts. Some discussion of alternative subsystem types, and the rationale for selection of subsystems, are contained on Section 4 of the report.

Although weighting has not been assigned to these criteria, such weighting will be necessary to obtain a quantitative overall evaluation. This step was not considered necessary at this stage of the concept development.

3.2 Building Block Configuration - Evaluation

3.2.1 User Accommodations Evaluation

3.2.1.1 Viewing

The building block Space Station configuration will provide for constant earth viewing at a 28.5° inclination. Both pressurized and unpressurized areas are provided for sensors. The pressurized areas would be for the earth sensors so that sensor development could be possible. The unpressurized areas are for solar and stellar viewing and the respective sensors are located in the surrogate payload bay. This location does offer viewing flexibility, insofar as stellar viewing frequency and orientation flexibility for both solar and stellar. However, additional study needs to be made to determine possible contamination due to payload bay location. It is possible to accommodate simultaneous earth, solar, and stellar viewing with this configuration.

3.2.1.2 Power

The power supplied to the user at IOC will be 60 KW continuous and at growth it will be 120 KW continuous.

3.2.1.3 Pressurized Volume

The pressurized volume at IOC provided to the user is two 22 foot modules. For growth, a total of four 22 foot modules and one 44 foot module are provided. The 44 foot module offers facility versatility in the growth phase and the two 22 foot modules offer flexibility at IOC. However, this is an issue; see Section 5.0.

3.2.1.4 Crew Time

A considerable amount of the crew's time has been allocated to the user as shown in sections 3.2.4, 3.3.4, and 3.4.4, each section pertaining to the building block configuration, delta truss configuration, and "T" configuration respectively.

3.2.1.5 External Attachments

A pallet attachment for the user is possible with this configuration.

3.2.1.6 Microgravity

The acceleration level at the modules that require low gravitational levels are assumed to be 10^{-4} g nominal. However, the effect of the module's distance from the station's c.g. has not been determined and needs to be considered for each configuration.

3.2.2 Crew Accommodations Evaluation

Due to the amount of equipment and the arrangement of the floor and ceiling, the C/C module only has the capability of having windows in one plane. It would be desirable to have windows capable of viewing all directions. Crew accommodations in the module are the WCS, a minimal galley, stored food for eight people for 22 days and a hygiene station. The accommodations are adequate.

If the manipulator is controlled from this module, the limited visibility will require additional windows or video equipment and perhaps at times, EVA crewperson to guide the manipulator.

The habitability module provides sleeping quarters, personal hygiene, medical facilities, and a galley/wardroom. The private sleeping quarter volume is adequate for sleeping, dressing, video training, and entertainment, grooming, and associated activities. It is generally preferable to have the sleeping

quarters located away from noisy equipment which would disturb a sleeping crew person. The habitability module does not entirely succeed in doing this, for adjacent to the sleeping quarters is the Personal Hygiene and Medical Facility. The Personal Hygiene area contains two combinations shower/urinal/handwash facilities and a Waste Control System (WCS). The Medical Facility contains limited medical equipment and supplies and the physical conditioning equipment. To make their location in the habitability module acceptable, the WCS and health maintenance equipment noise levels must be sufficiently low to avoid disturbing a sleeping crewperson or special accoustical isolation must be provided. The Personal Hygiene Facility coupled with a WCS in the Command and Control Module is adequate for eight crewpersons. The galley and wardroom provide facilities for use by eight crewpersons simultaneously which is adequate. The wardroom area should provide a capability for group training or entertainment.

For growth, a second similar habitability module is added to the station and the medical/physical conditioning equipment is moved to the Life Sciences Lab. The second habitability module is adequate for the increase in crew.

The habitability module is designed to permit unimpeded passage through the module. The module maintains a consistent heads-up orientation which is desirable. The floor and ceiling are offset from the module walls to allow utility equipment location. This combination renders it difficult to locate windows in these areas and consequently there are none. (It would be desirable to have windows which could view in all directions.)

3.2.3 Engineering

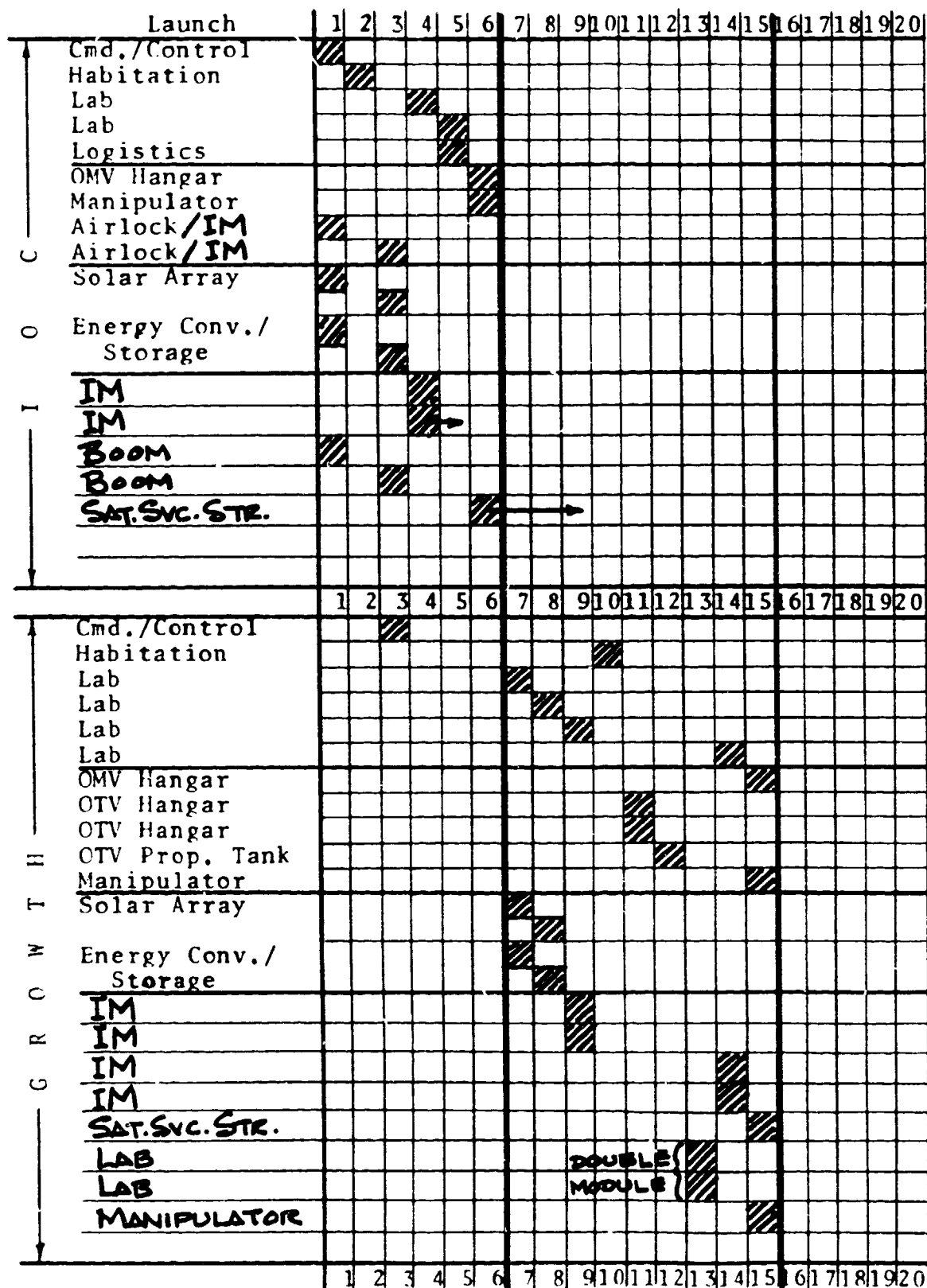
3.2.3.1 Assembly and Growth Evaluation

A preliminary launch-by-launch buildup sequence has been developed and is

BUILDUP SEQUENCE

Configuration BUILDING BLOCK

Date 12/1/83



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Figure 3.2.3.1-1

summarized in figure 3.2.3.1-1. This sequence is based on Orbiter payload bay packaging that is plausible but optimistic. It is assumed that an Orbiter docking module is carried on all flights. Where possible, all elements are installed initially in their final locations. Exceptions are indicated in figure 3.2.3.1-1 by an arrow from the flight that launches the element to the flight on which it is moved to its final location. Completion of IOC and growth capabilities is denoted by heavy vertical lines.

Figure 3.2.3.1-2 illustrates the assumed packaging in the payload bay for each launch required for IOC.

3.2.3.1.1 User Accommodation: Assembly and Growth

Preliminary investigation of the buildup process makes clear that the compact arrangement of the building block configuration leaves little latitude for alternate element locations. When two Orbiter berthing locations are left open, few useable ports remain for future, presently unidentified applications. Within the bounds of the building block concepts, user accommodations might be exchanged for different ones with little difficulty. Providing additional facilities would be less easy.

3.2.3.1.2 Systems Engineering: Assembly and Growth

It is assumed that work requiring a low-gravity environment will be suspended during any station assembly operations, and therefore that this is not a discriminator. However, large attitude changes can be anticipated when an Orbiter is berthed to the station; orientation-sensitive work will suffer accordingly. One satellite service structure must be relocated during buildup and its function would also be temporarily suspended at that time.

Transition efficiency also suffers from the relocations required. The IM relocation could be eliminated but a less economical launch packaging scheme

would probably be needed. The service structure relocation cannot readily be avoided.

There are no elements in the early phase that are discarded in later stages. Assembly requires the full capability of the Orbiter RMS. A second RMS or a handling and positioning aid will be needed in some steps of buildup. EVA can be limited to service structure and hangar assembly for IOC, but will be required for power system installation in the growth phase. With suitable detail design, disassembly can be handled similarly. Note that the RMS reach analysis in section 3.2.4.2 assumes a large manipulator on the station at an early point in the buildup in lieu of a handling and positioning aid.

Once the station is built up, any pressurized module will be very difficult to remove and replace. In most cases, partial disassembly will be necessary.

The structural characteristics of the station will be degraded, to an extent not yet determined, until the module is replaced.

Two ports are available at all times for Orbiter berthing, as specified in the system requirements. Two additional ports can be used by the Orbiter but offloading of payloads would be restricted, if possible at all. Twelve other ports could be used by temporary payloads but the rotating radiators will severely limit the length of a payload at most of these ports.

3.2.3.1.3 Programmatics: Assembly and Growth

In the buildup sequence, IOC is reached after six launches. Redundancy of essential systems is achieved after three launches and the station could be permanently manned at that time. Lack of a logistics module would limit crew size to that supportable by consumables stored in the C/CM and HM, and absence of a LM would constrain the useful work that could be done. The latter constraint is eliminated on the fourth launch. Five launches provide full IOC except for OMV support and an on-board manipulator.

Total deployment of the growth capability requires 15 launches in the scenario assumed. If the OMV and OTV hangers can be packaged compactly enough, it may be possible to reduce this number by one launch. Another launch might be saved if tunnels were substituted for the two LM's in excess of the specified requirements. Thus, it may be possible to achieve a minimum growth station in 13 launches not counting resupply flights.

3.2.3.1.4 Safety: Assembly and Growth

The compact configuration of the building block makes it impossible to achieve large separations between inhabited areas and hazardous areas such as the OTV propellant storage facility. In the reference configuration, the propellant tank is directly adjacent to a LM and is only 50 feet from an HM. By a major module rearrangement, the distance to the HM could be increased to 90 feet. Isolation of a hazardous conditions, such as a spill of a toxic substance, can be done with little difficulty. Since there are two routes to each modules, any one can be isolated without significant disruption of other activities.

3.2.3.2 Structural Dynamics and Control Evaluation

3.2.3.2.1 Building Block Configuration Flight Mode

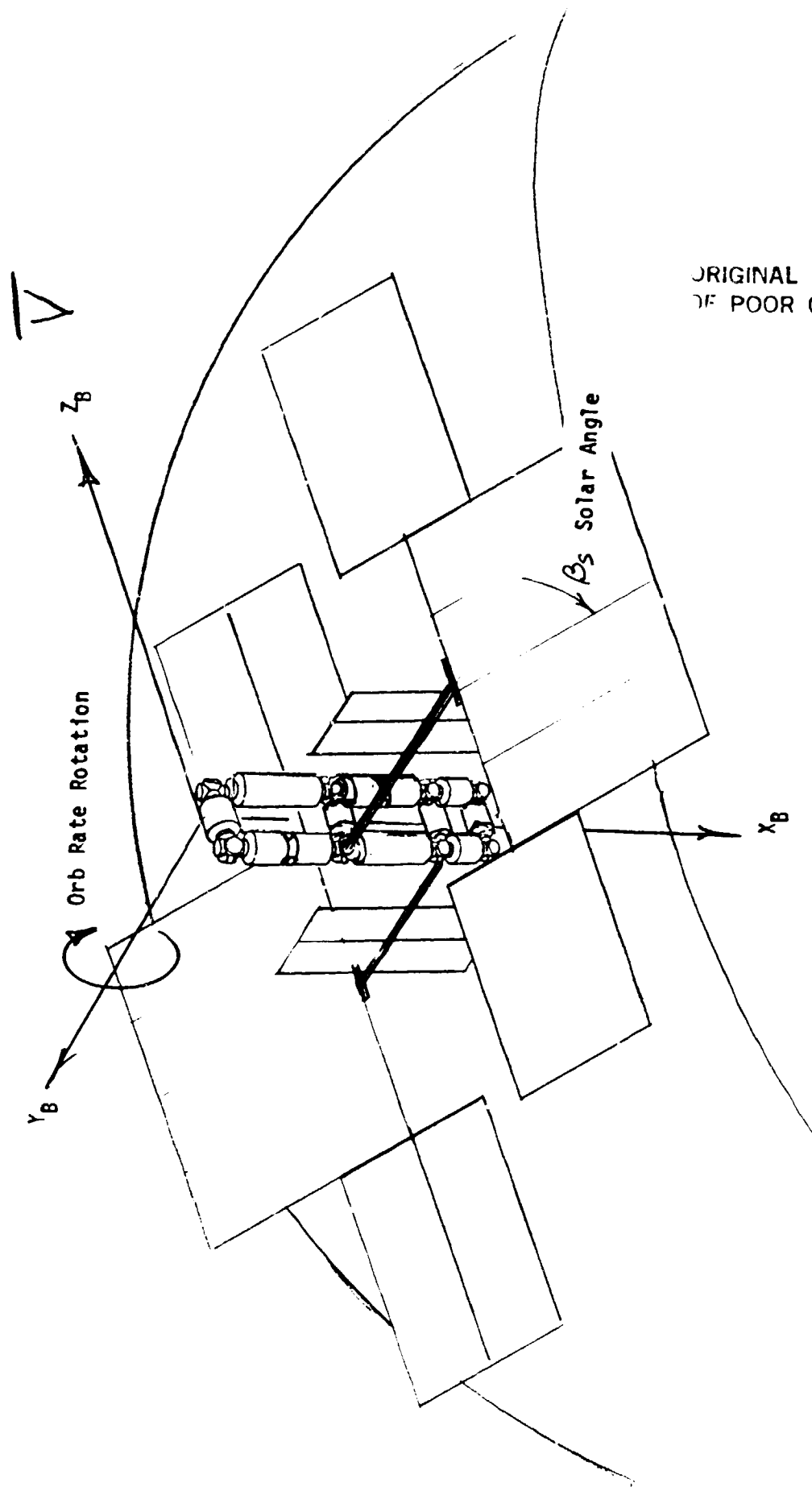
The Building Block configuration (BB) has been designed to fly with its body axes basically aligned with the LVLH axes (local vertical local horizontal), see figure 3.2.3-1. In this flight mode, the BB configuration is pitched in the orbit plane to achieve a Torque Equilibrium Attitude (TEA) condition. Since the aerodynamic and gravity gradient torque vary as a function of solar array position, iteration to an average TEA can be quite lengthy.

The BB configuration is rolled to place the average principal axes perpendicular to the orbit plane. Next, the BB configuration is pitched slightly in the orbit plane until an average TEA is obtained. TEA is

achieved when the pitch plane gravity gradient torque is cyclic due to the solar array being held solar inertial while the BB configuration modules are held in a modified LVLH attitude. A final yaw adjustment is made to null the secular torques. Control moment gyro's (CMG's) null the resulting cyclic torques to maintain the flight attitude.

3.2.3.2.2 On-Orbit Disturbances - Gravity Gradient

Operation in low earth orbit (270 NM) provides exposure to significant gravity gradient torque disturbances. These are on the order of two foot pounds. While relatively insignificantly from a controllability point of view, the extreme time span of the Space Station mission makes these significant drivers for "cost-of-ownership," unless the steps are taken to minimize their influence.



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Figure 3.2.3.2-1 BBC Flight Orientation

3.2.3.2.3 Aerodynamic Torque Disturbance

In addition to gravity gradient torques, the aerodynamic torques can produce secular momentum accumulation. Detailed simulation of the aerodynamic disturbance for the BB configuration has been conducted. However, the asymmetric effect of the diurnal atmosphere variation has been neglected for this analysis. The BB configuration has solar inertial fixed panels which produce significant drag forces. However, the full up BB-IOC and GROWTH configurations have small pitch plane torque moment arms. Thus a small pitch plane attitude alignment change can be made to fly an average TEA.

3.2.3.2.4 Mass Properties Management

A mass properties management scheme must be employed in the Space Station design in order to enhance the flight performance. The mass properties for the BB configuration are shown below:

	IOC	GROWTH	
IXXP	1.44 E 7	2.1 E 7	Slug-ft ²
IYYP	.93 E 7	6.8 E 7	Slug-ft ²
IZZP	1.62 E 7	7.0 E 7	Slug-ft ²
0 _x *	-4.2°	-25.6°	
0 _y *	-11.7°	-10.25°	
0 _z *	-29.2°	-2.0°	
R _x	89.6	92	ft
R _y	-.25	-.4	ft
R _z	-5.4	2.3	ft
	211.3K	756.8K	

* Euler angles; rotate from generated axes to principal axes with rotation order 0_x, 0_y, and 0_z. R_x, R_y, R_z, cg-vector position, IXXP, IYYP, IZZP principal inertias.

3.2.3.2.5 Momentum Storage Requirements

Momentum storage requirements are based upon the peak cyclic momentum variations, and the attitude control system philosophy regarding the amount of reliance on the CMG's for attitude maneuvers and absorption of large impulsive disturbances (i.e, mix between CMG torque impulse and RCS torque impulse). Peak cyclic momentum storage for the BB configuration due to aerodynamics torques and gravity gradient torques are presented below. Due to the time available for this study, the momentum storage equipment was sized only for the nominal flight conditions involving attitude hold.

PEAK CYCLIC GRAVITY GRADIENT MOMENTUM (FT-LB-SEC)

FLIGHT MODE	IOC	<u>BB</u> GROWTH
EARTH FIXED	9,000	12,500

3.2.3.2.6 Orbital Maintenance Impulse Requirements

Orbital maintenance impulse was determined using the NASA neutral atmosphere (SP-8021) density at 270 NM and average aerodynamic properties to compute the drag impulse. The NASA neutral atmosphere is considered to be the worst long-term atmosphere applicable to a 90-day resupply cycle. Short term maximum conditions should be used for RCS engine magnitude sizing.

The disturbance simulation used a dynamic pressure of $.99905E-6 \text{ lb/ft}^2$.

summary results for the BB configuration are shown below.

DRAG IMPULSE PER ORBIT LB-SEC/ORBIT

Configuration	BB Configuration
Flight Mode	IOC Growth
Earth Fixed	240 480

Using the data shown above, worst case resupply propellant for altitude maintenance was calculated and shown below. This assumes that the orbit is

not allowed to deviate from 270 NM.

90-DAY RESUPPLY PROPELLANT FOR ALTITUDE MAINTENANCE FOR 270 NM
LBS - (NORMALIZED TO: ISP = 220 SEC.)

Configuration	BB Configuration	
Flight Mode	IOC	Growth
Earth Fixes	1,500	3,000

For the earth fixed attitude mode, the BB configuration suffers a distinct disadvantage due to the fact that the large solar panel areas are not always "feathered."

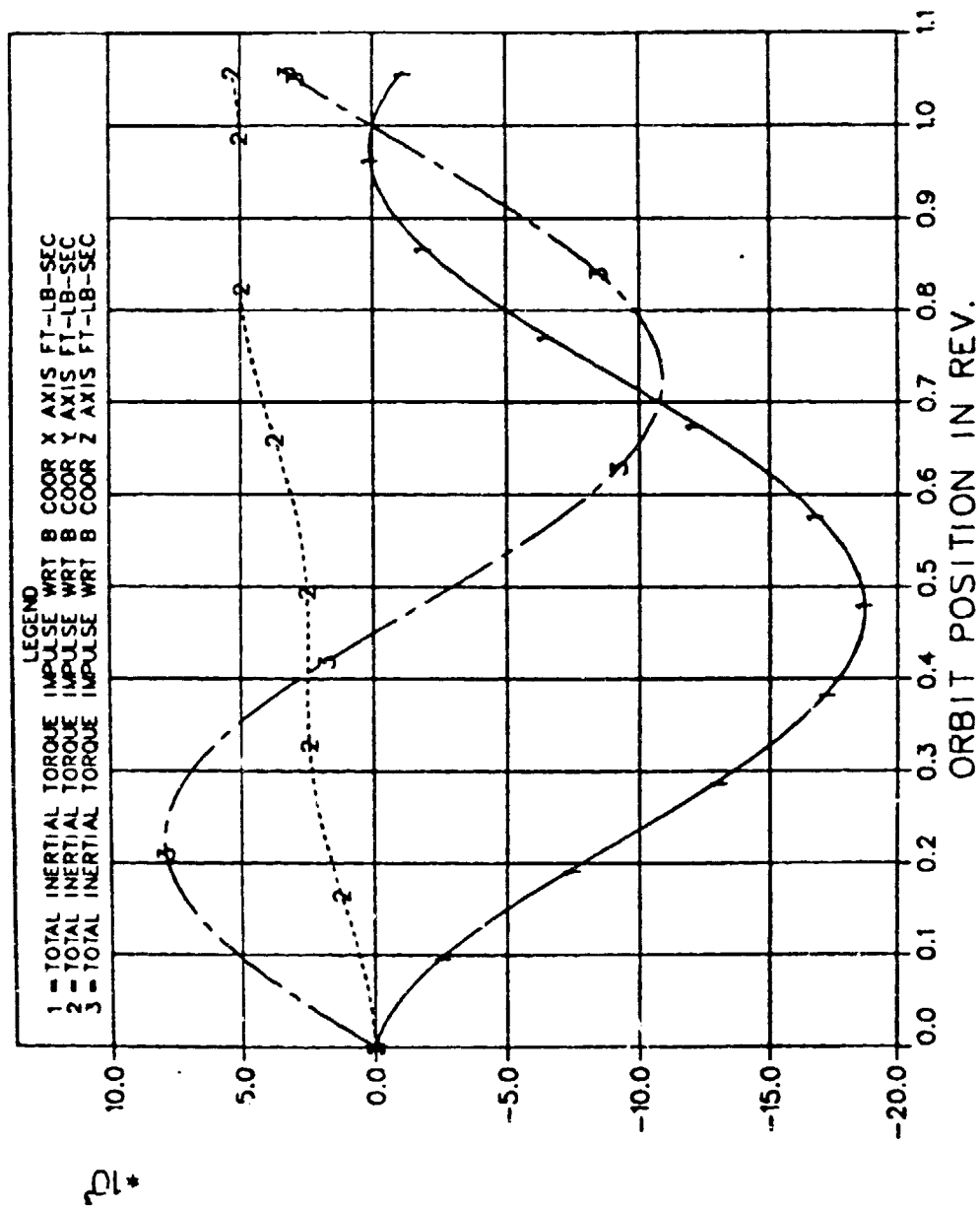
3.2.3.2.7 RCS Firing Frequency

Detailed flight dynamic simulations of the BB configuration show that the configuration can be trimmed so that there is no secular torque momentum acculation per orbit. Thus, no RCS firings are required for CMG desaturation. The BB configuration can achieve a minimum RCS attitude maintenance firing frequency of once every 90 days chosen to coincide with STS resupply. This will be particularly attractive to long term low "g" scientific experiments and manufacturing processes. Attitude loss will be less than seven miles in 90-days.

3.2.3.2.8 Result of BB-IOC On-Orbit Flight Dynamics

The results of the on-orbit flight dynamics for the BB-IOC configuration in the LVLH flight mode are shown in figure 3.2.3.2-3 through 3.2.3.2-6. Figure 3.2.3.2-2 shows the torque impulse history of the BB-IOC configuration for one orbit. The torque impulse curve shows a slight TEA mis-trim condition of 5,000 ft-lbs-sec per orbit. Additional iterations can be made to null the TEA imbalance. The cyclic momentum storage requirement will not change significantly with further iterations and is approximately 9,000 ft-lbs-sec.

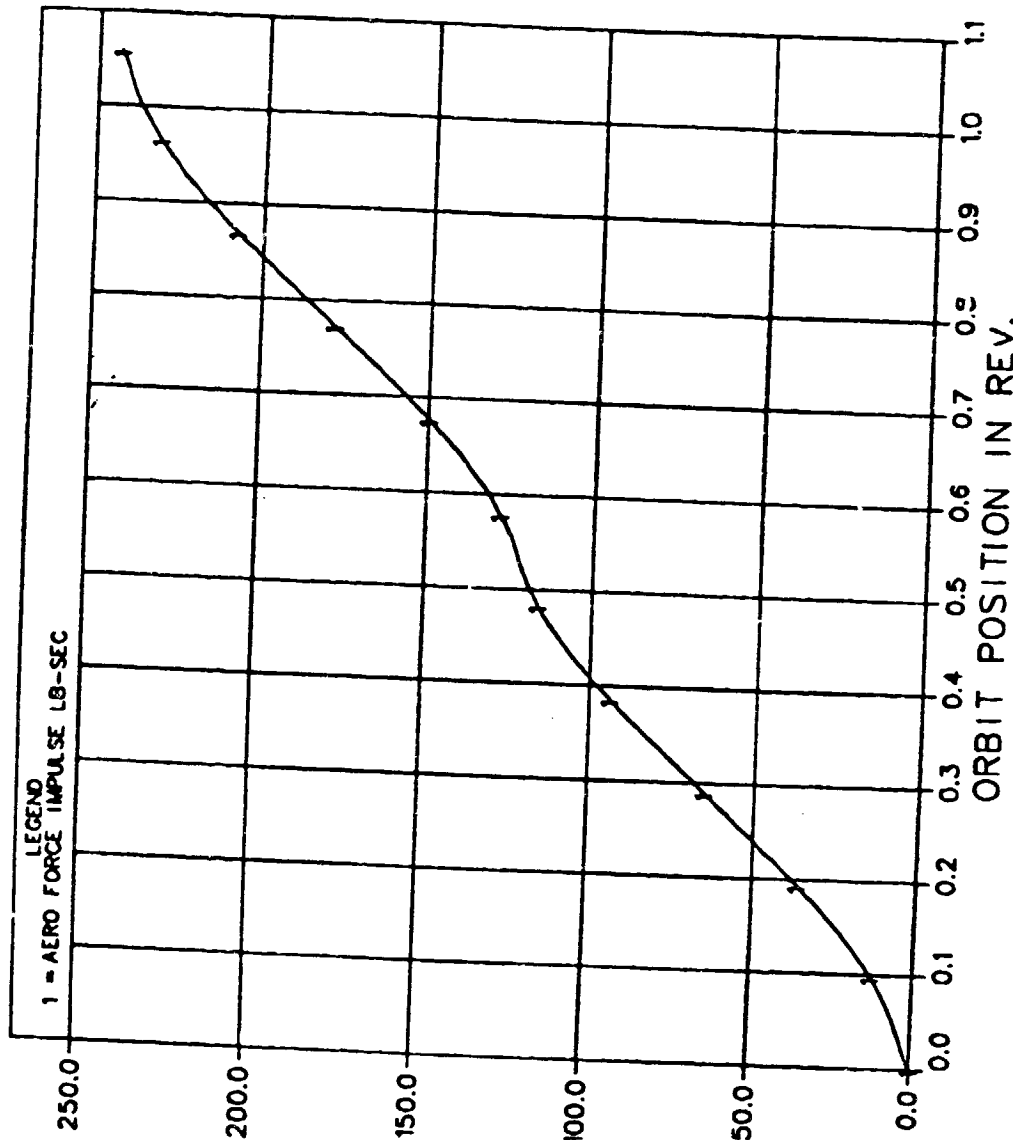
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Figure 3.2.3.2-2 BBC-I0C Momentum Accumulation Time History

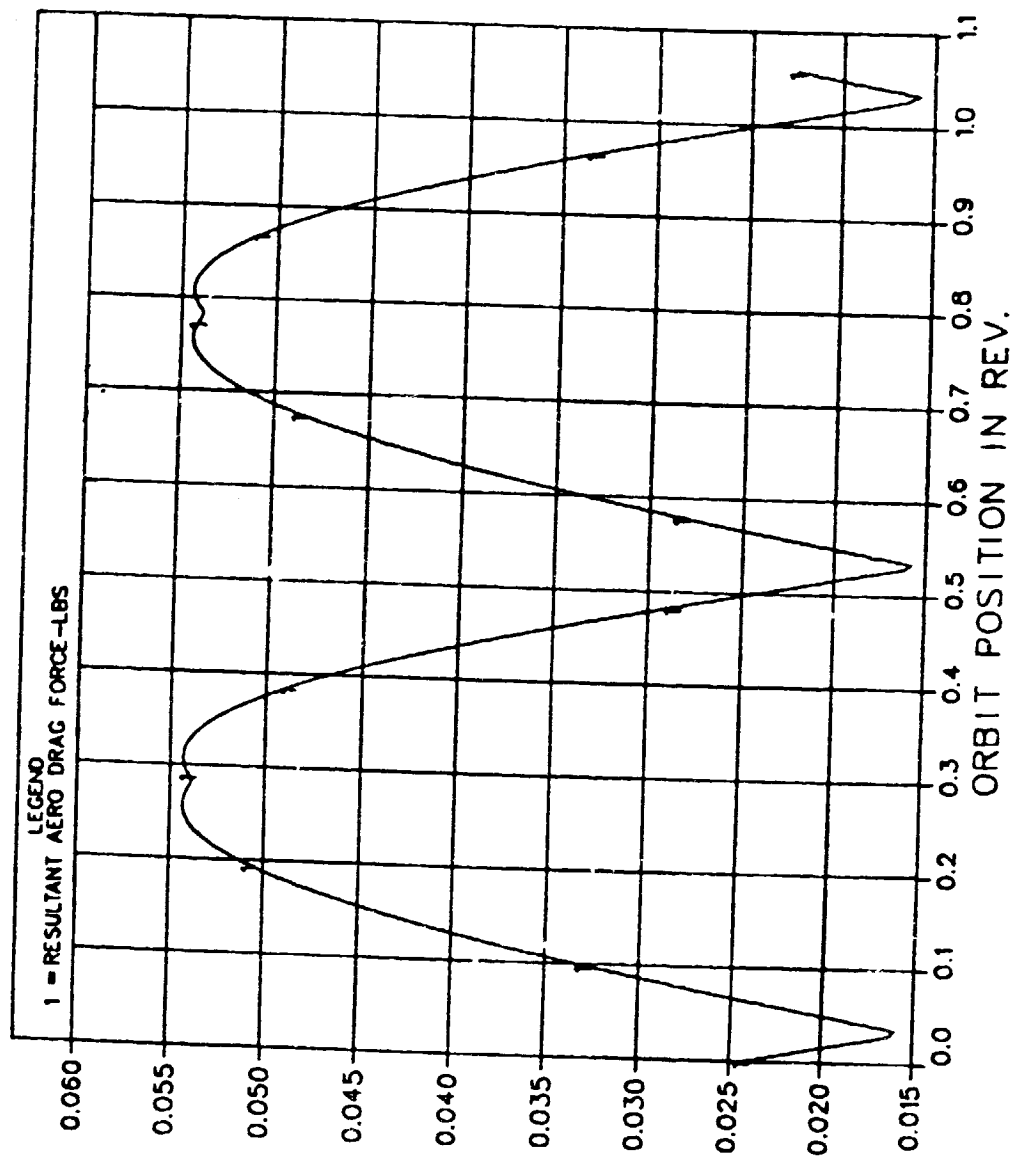
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Figure 3.2.3.2-3 BBC-IOC Aerodynamic Drag Impulse Time History

SOC=IOC,INCL=0.0,PITCH=101.7,ARRAY=0,ORB RATE YC AXES

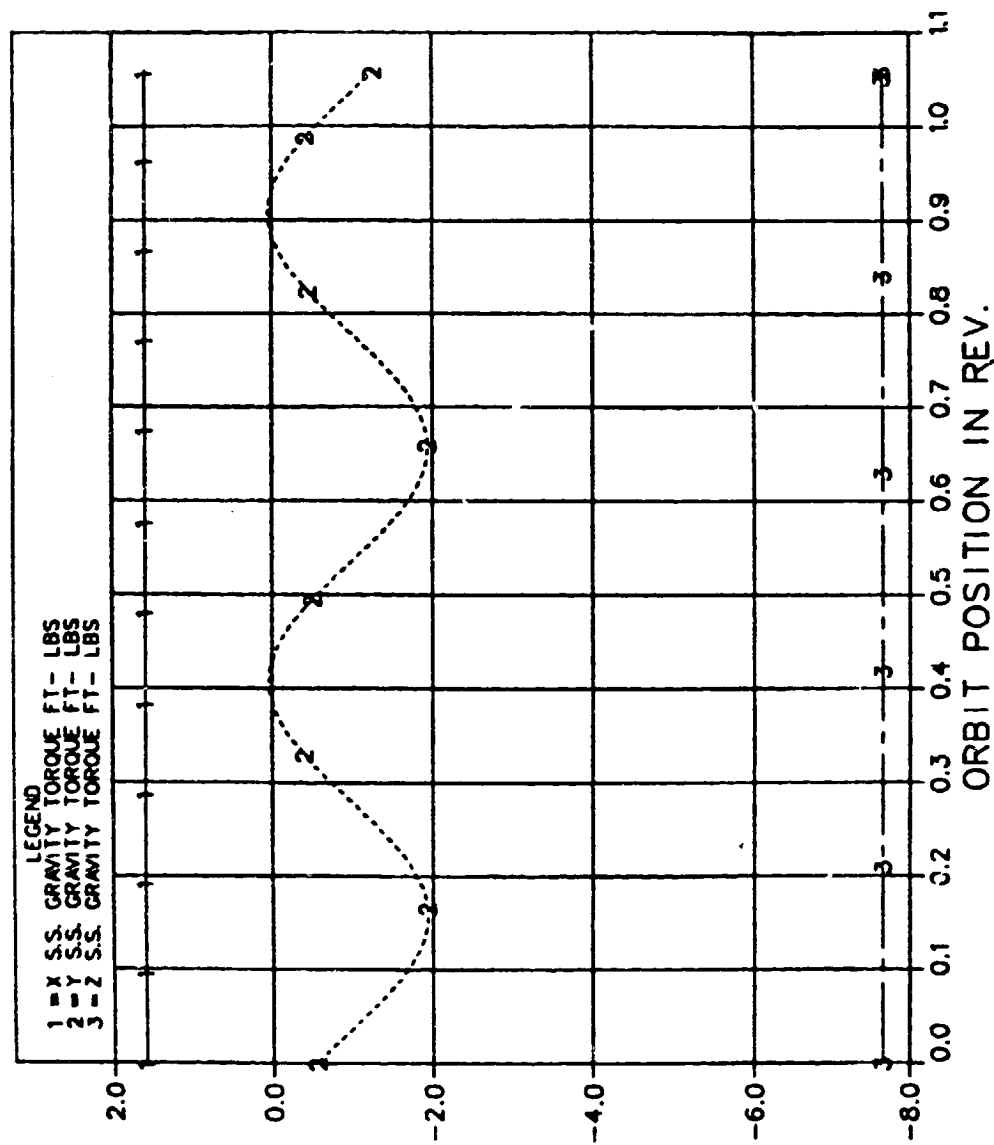


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Figure 3.2.3.2-4 BBC-IOC Total Aerodynamic Drag Force Time History

SOC=IOC, INCL=0.0, PITCH=101.7, ARRAY=0, ORB RATE YC AXES



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Figure 3.2.3.2-5 BBC-IOC Total Gravity Gradient Torque Time History

The aerodynamic drag impulse history shown in figure 3.2.3.2-3 is 240 lbs-sec/orbit. Figure 3.2.3.2-4 shows the resultant drag force history which peak at .054 lbs. Figure 3.2.3.2-5 shows the gravity gradient torque history whose cyclic torque peaks at two foot lbs. Figure 3.2.3.2-6 shows the aerodynamic torque history which has a peak pitch torque of .13 ft-lbs.

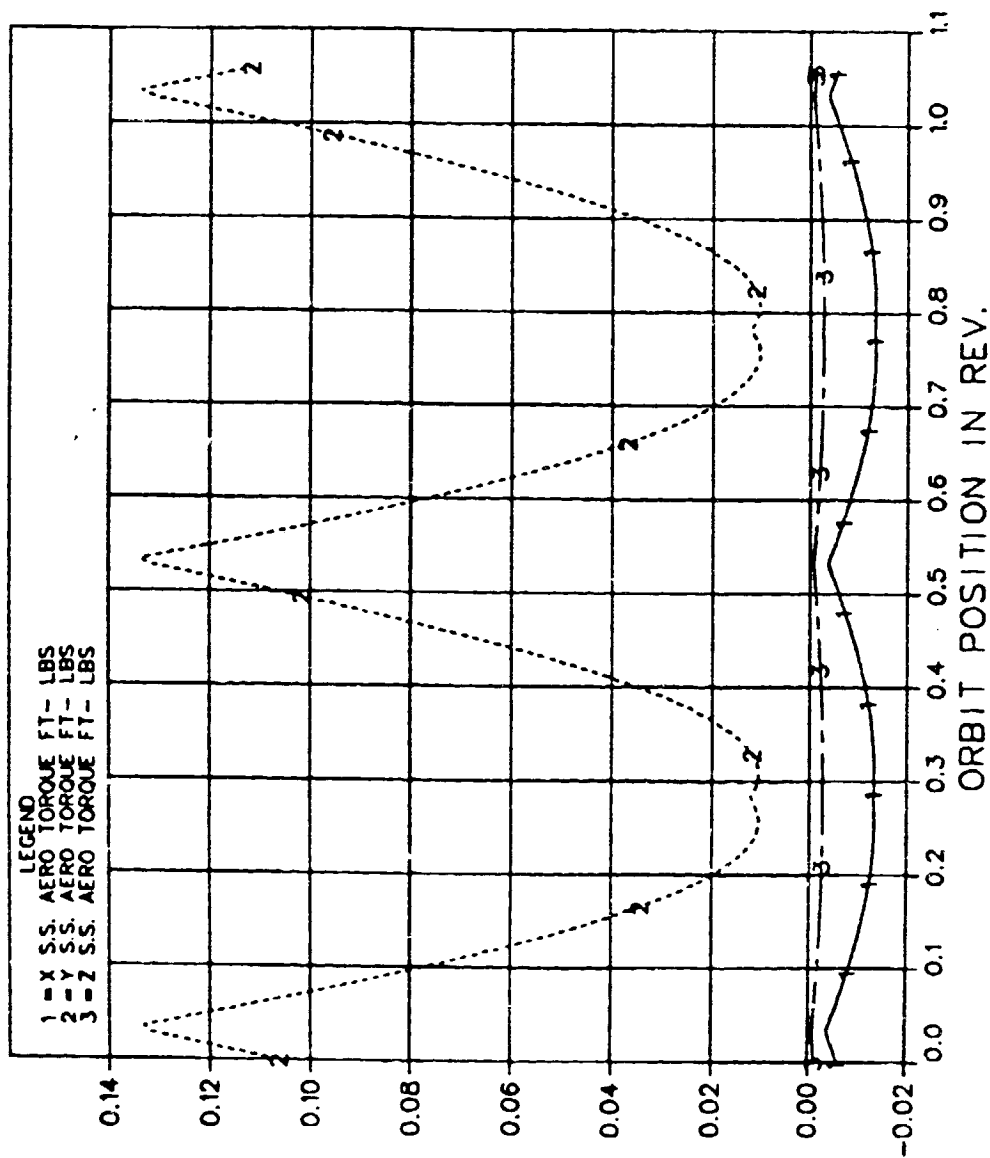
3.2.3.2.9 Results of BB Configuration Growth On-Orbit Flight Dynamics

The results of the on-orbit flight dynamic for the BB-Growth configuration in the LVLH flight mode are shown in figure 3.2.3.2-7 through 3.2.3.2-10. Figure 3.2.3.2-7 shows the torque impulse history of the BB-Growth configuration for one orbit. The torque impulse curve shows a slight TEA mistrim condition of 2,000 ft-lbs-sec per orbit. Additional iterations can be made to null the TEA imbalance. The cyclic momentum storage requirement will not change significantly with further iterations and is approximately 9,000 ft-lbs-sec. The peak storage requirements of 12,500 ft-lbs-sec occurs when the solar arrays are tilted 45° . The aerodynamic drag impulse history shown in figure 3.2.3.2-8 is 5,000 lbs-sec/orbit. Figure 3.2.3.2-9 shows the resultant drag force history which peak at .13 lbs. Figure 3.2.3.2-10 shows the gravity gradient torque history whose cyclic torque peaks at .17 ft-lbs. Figure 3.2.3.2-8 shows the aerodynamic torque history which has a peak pitch torque of .75 ft-lbs.

3.2.3.2.10 Structural Dynamics and Control

The flexibility of a Space Station is analyzed because of its contribution to internal and module interface loads. Also, excessive dynamic accelerations, velocities, and displacements can degrade the performance of sensitive instruments (or experiments) and complicate vehicle maneuvers. This section of the report summarizes the structural dynamics of the BB concept and the effects this flexibility has on the flight control system.

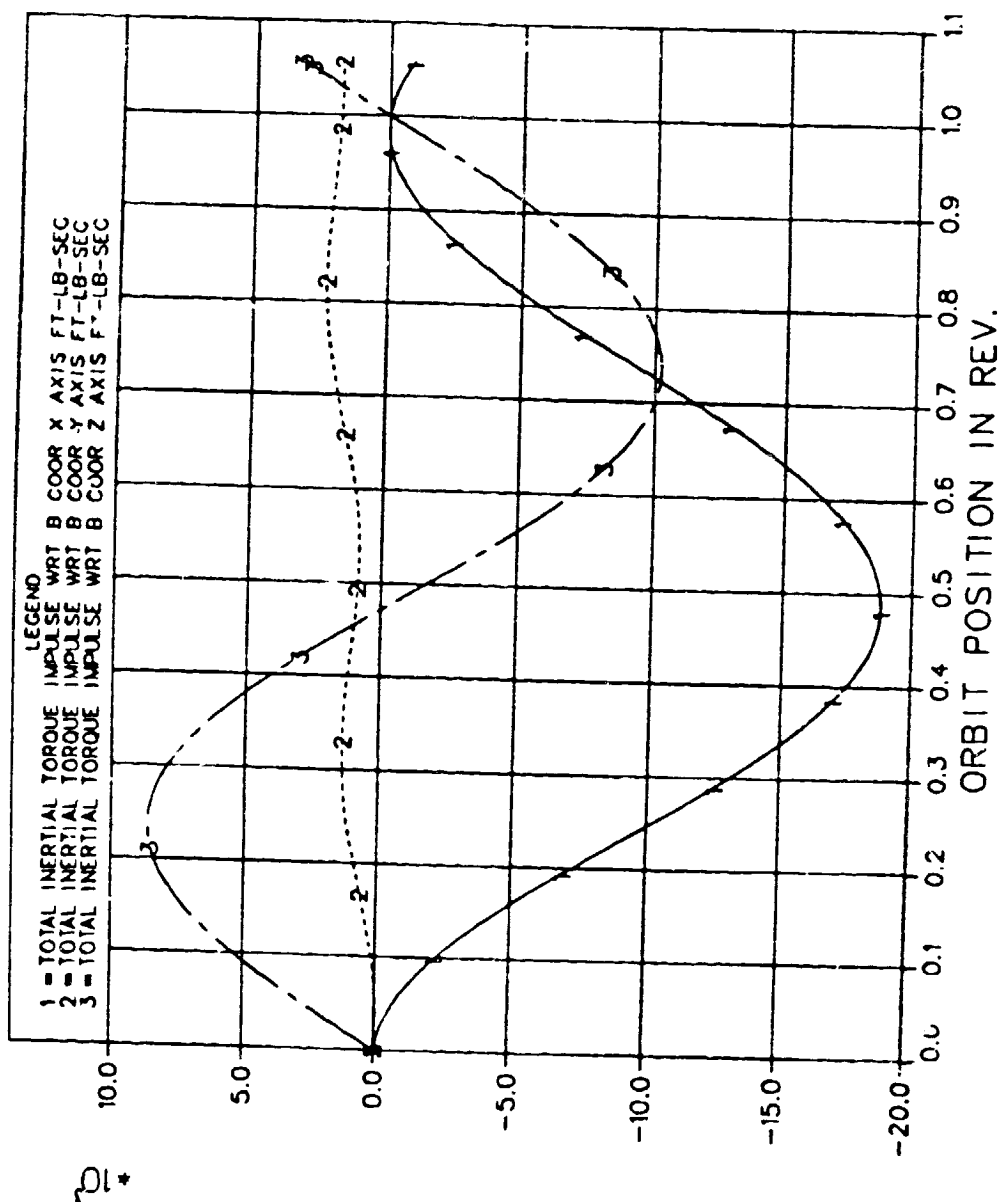
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Figure 3.2.3.2-6 BBC-IOC Aerodynamic Torque Time History

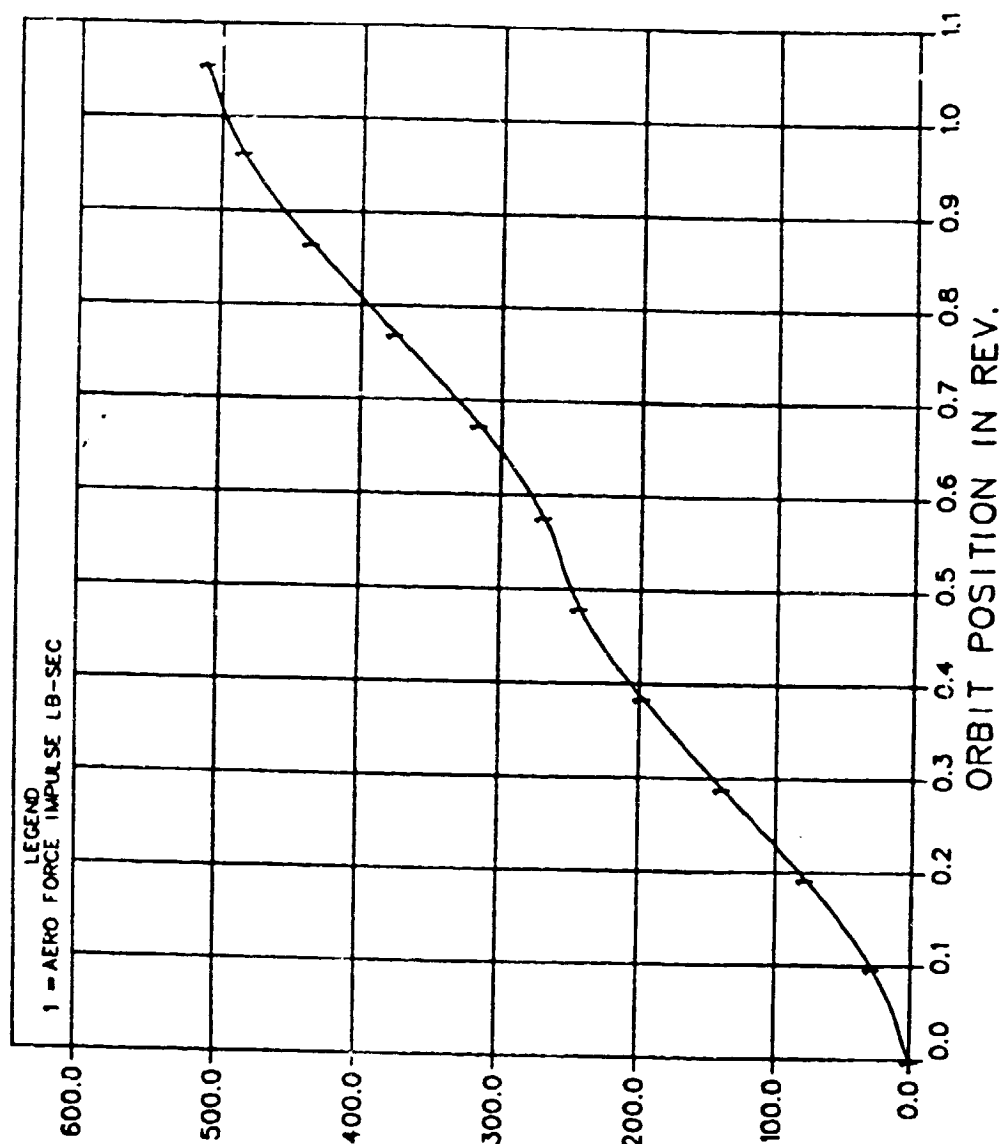
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Figure 3.2.3.2-7 BBC-GROWTH Momentum Accumulation Time History

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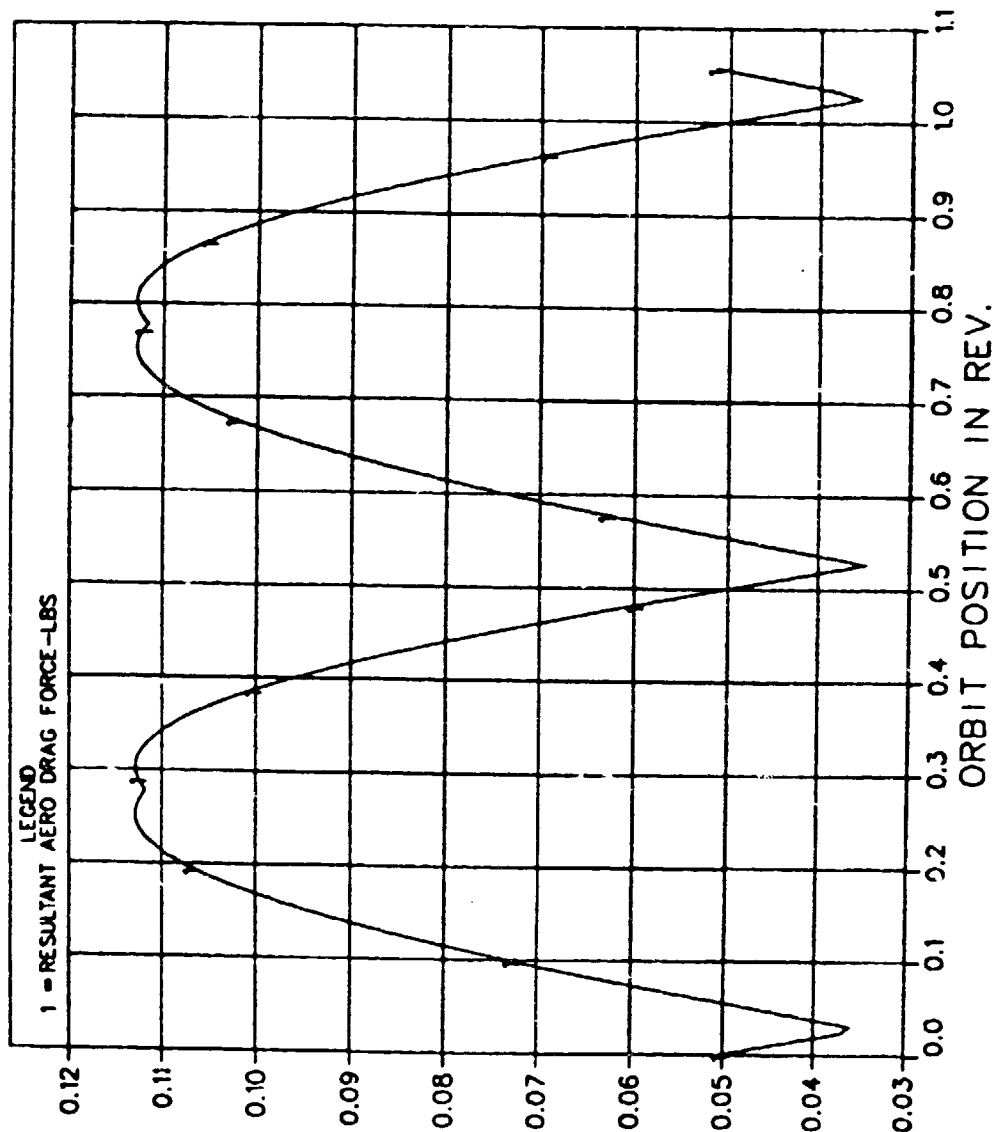
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Figure 3.2.3.2-8 BBC-GROWTH Aerodynamic Drag Impulse Time History

C.2

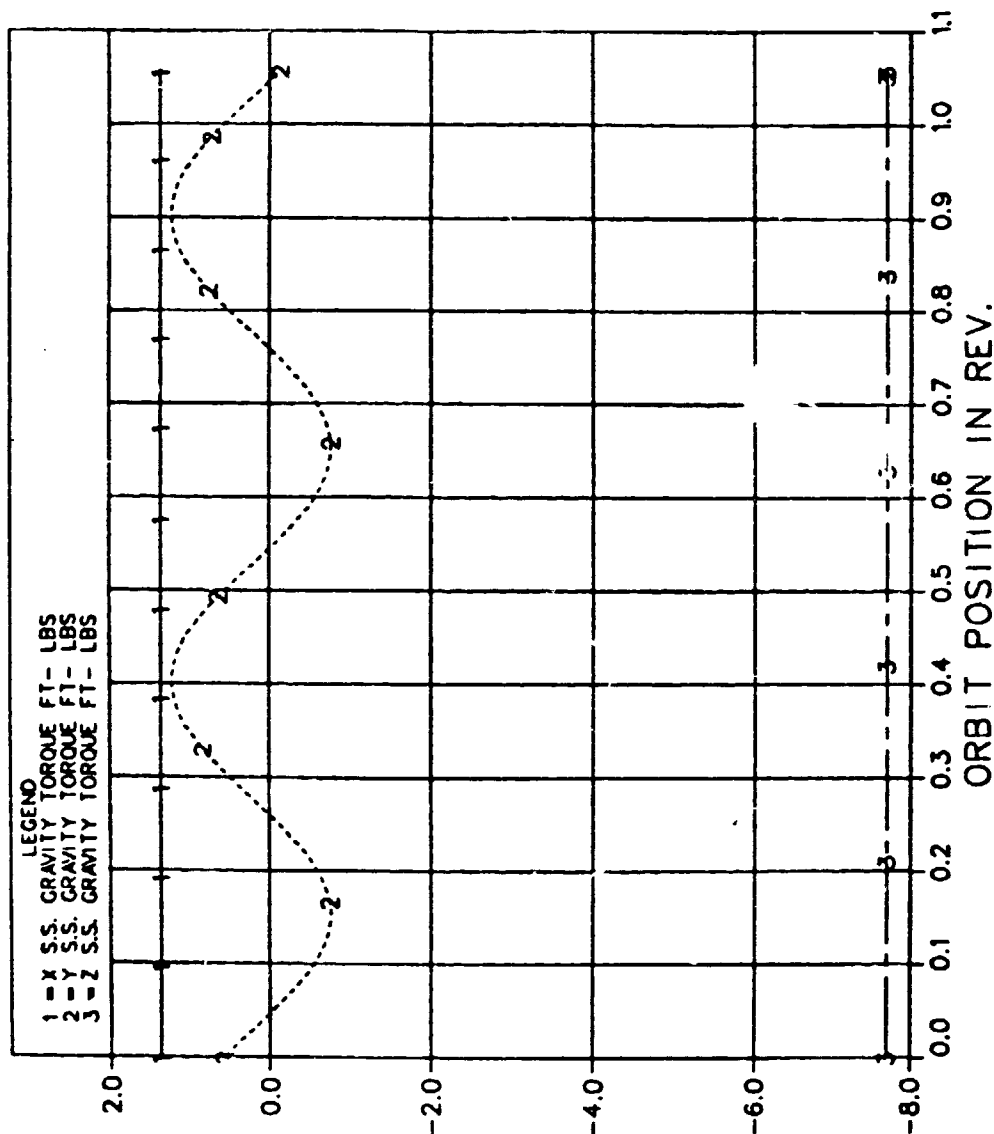
SOC-G, INCL=0.0, SUN=-52, ARRAY=0, ORB RATE YC AXES



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Figure 3.2.3.2-9 BBC-GROWTH Total Aerodynamic Drag Force Time History

SOC-G, INCL=0.0, SUN=-52, ARRAY=0, ORB RATE YC AXES



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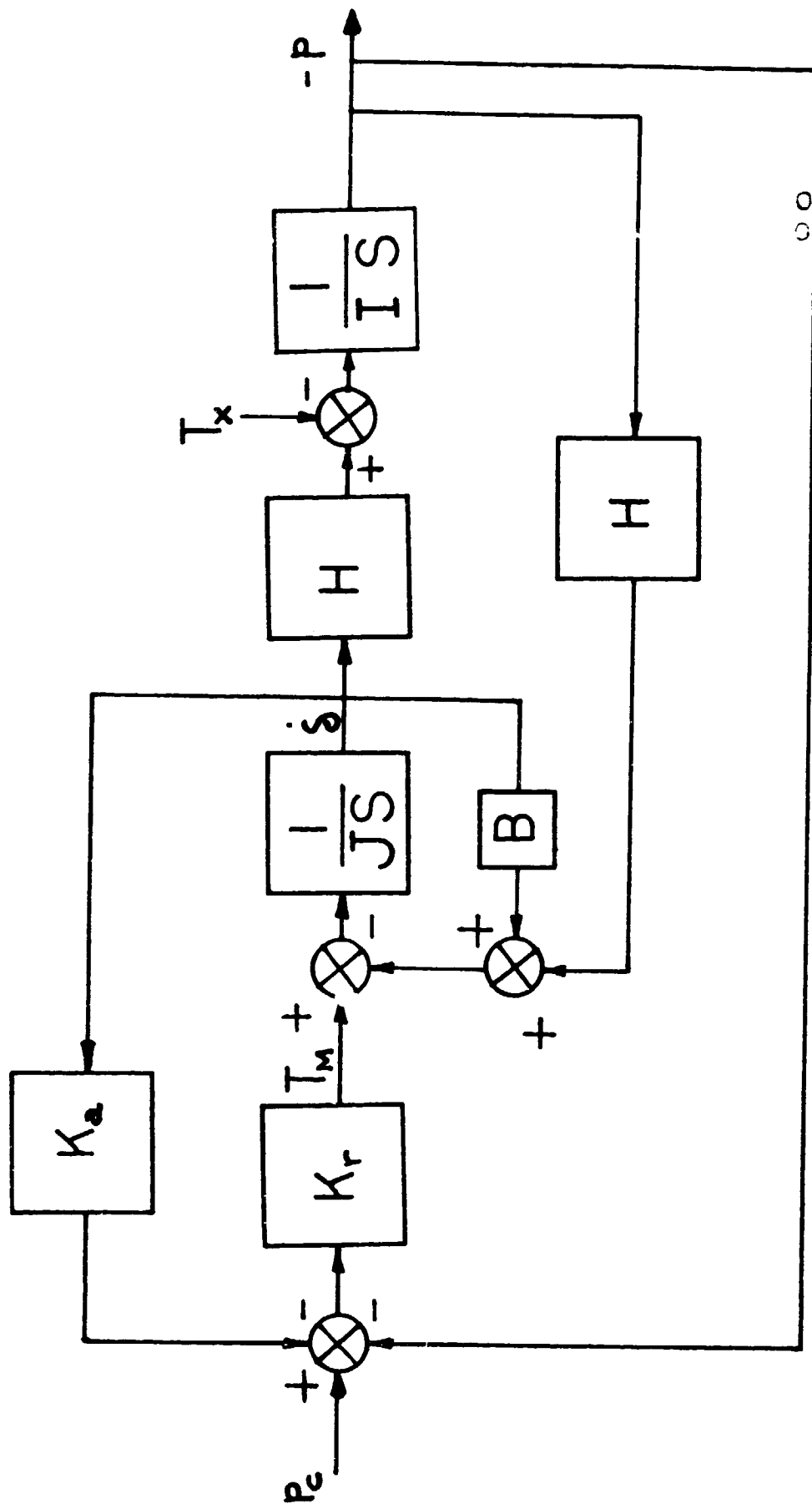
Figure 3.2.3.2-10 BBC-GROWTH Total Gravity Gradient Torque Time History

(+)

The BB configuration was found to have a low natural frequency with array bending (0.07 Hz). An interesting dynamic response results from the asymmetry of the array as attached to the station. This asymmetry creates an additional low frequency rotation about the array axis which contributes to the already complex control strategy necessary for this configuration.

A single axis rigid body control analysis was performed for the BB configuration that utilized the maximum moment of inertia in the vehicle dynamics model, figure 3.2.3.2-11. A second order model was assumed for the CMG and angular rate dynamics. The resulting closed loop system has nearly critically damped CMG/rate poles near the open loop values. A frequency response (Bode plot) was made to determine the control system pass band. The BB configuration controller was found to have bandpass to 0.6 Hz. This value is higher than the other configurations and is attributable to the rotational inertia of this system. The higher bandpass implies a faster time response for maneuvers.

Comparing the structural flex spectrum with the controller bandpass reveals considerable overlap of the dynamics for each subsystem. The BB configuration has a first bending mode at 0.07 Hz and is followed by seven additional modes that reside inside the controller bandpass. (The mode shapes that reside in the controller bandpass are included in figures 3.2.3.2-12 through 3.2.3.2-19). The overlap in frequency response of these systems dictate the use of sophisticated control methods. Several approaches to this control problem have been identified. Distributed vibration control, OEX DAP



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LINEARIZED MODEL

FIGURE 3.2-11

MODE NO. 14
FREQUENCY = 0.57 HZ



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ALPHA = -90.0 DEG
BETA = 0.0 DEG
GAMMA = 30.0 DEG

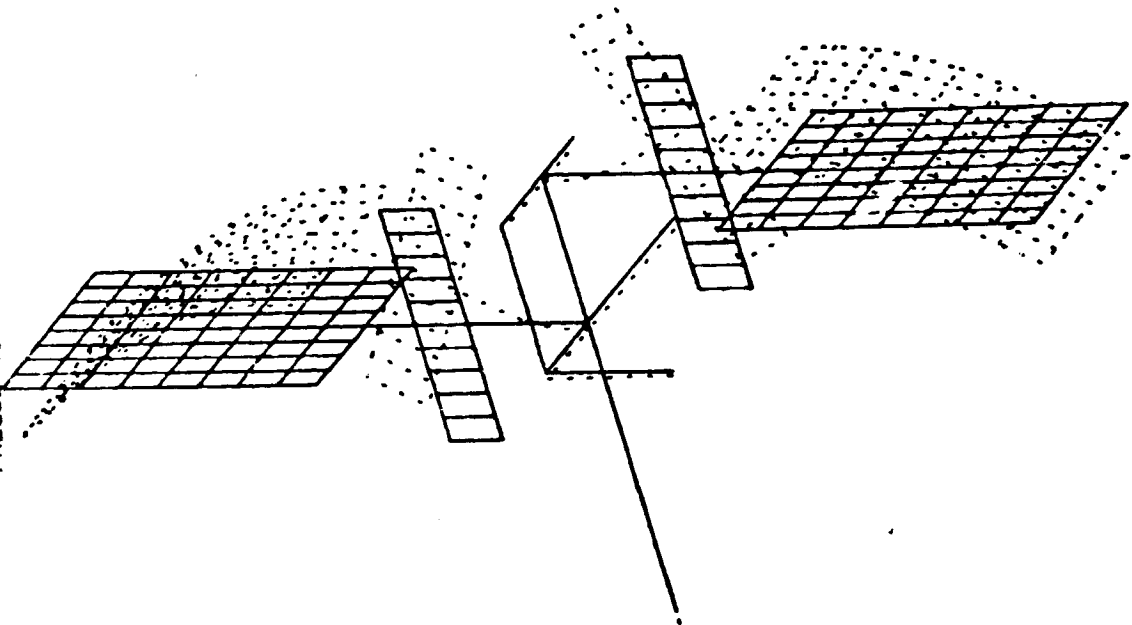
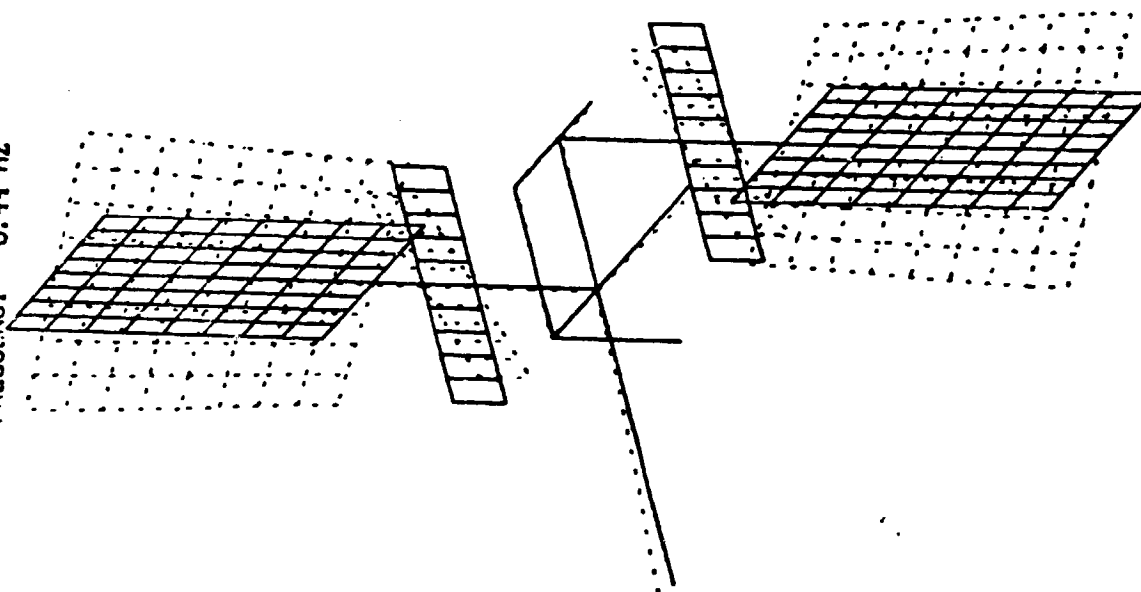


Figure 3.2.3.2-12 Flex Mode Within Control System Passband

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12/12/83 JBR

MODE NO. 12
FREQUENCY = 0.44 HZ



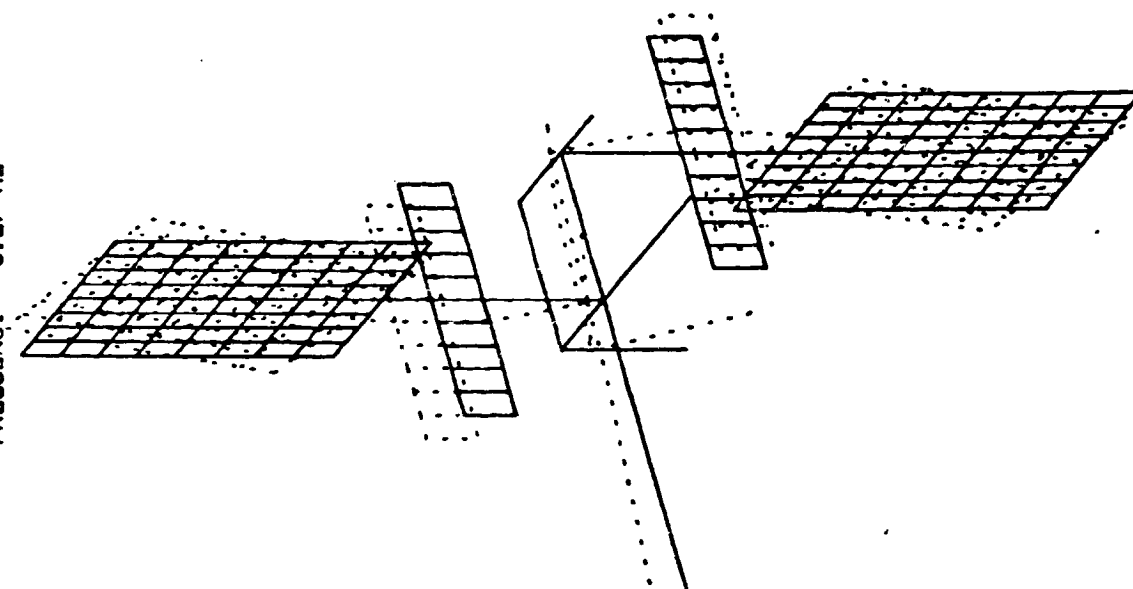
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ALPHA = -90.0 DEG
BETA = -90.0 DEG
GAMMA = 90.0 DEG

JOHNSON SPACE CENTER
STRUCTURAL MECHANICS BRANCH
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Figure 3.2.3.2-13 Flex Mode Within Control System Passband

MODE NO. 10
FREQUENCY - 0.27 HZ



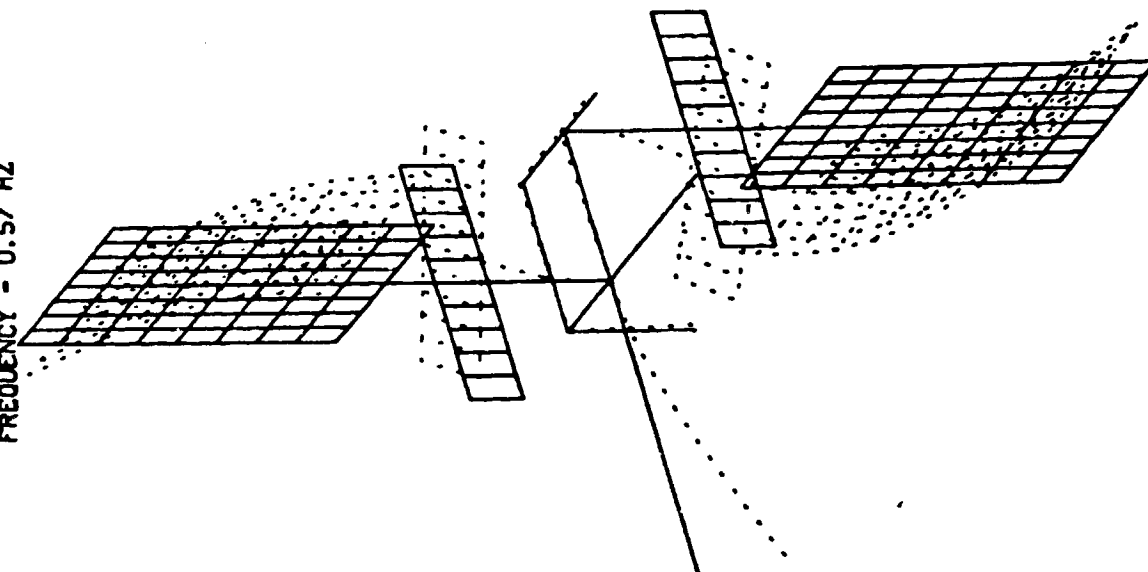
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MODE NO. 10
FREQUENCY - 0.27 HZ
MODE NO. 11
FREQUENCY - 0.27 HZ

Figure 3.2.3.2-14 Flex Mode Within Control System Passband

JOHNSON SPACE CENTER
STRUCTURAL MECHANICS BRANCH
12/12/80

MODE NO. 13
FREQUENCY = 0.57 HZ



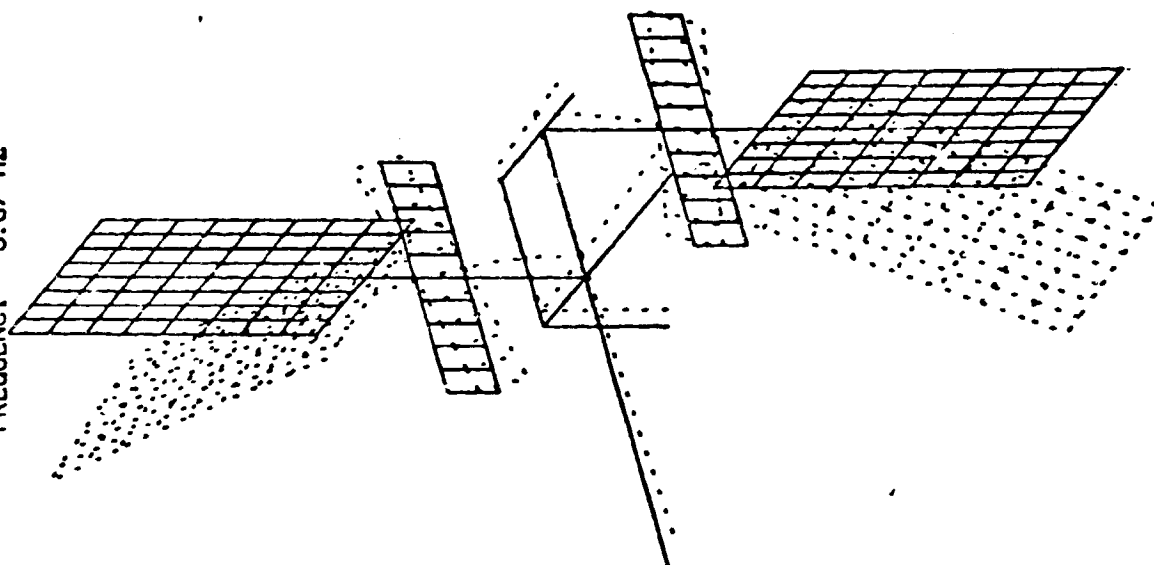
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$\sum x = 0.0$
 $\sum y = 0.0$
 $\sum z = 0.0$

Figure 3.2.3.2-15 Flex Mode Within Control System Passband

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 STRUCTURAL MECHANICS BRANCH
 12/12/63 JCR

MODE NO. 7
FREQUENCY = 0.07 HZ



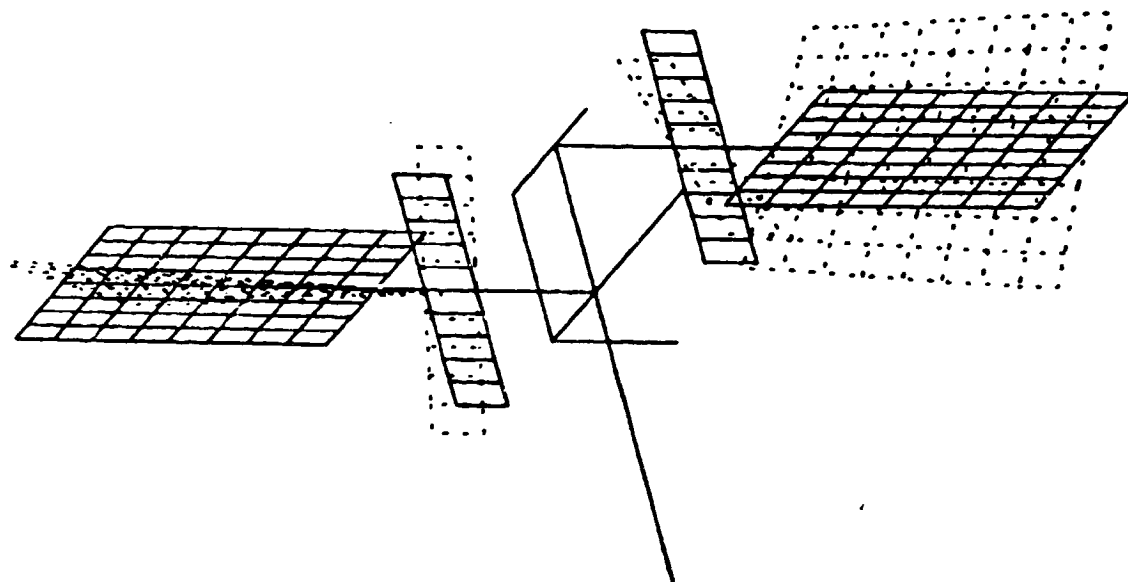
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MAX = 0.000
MIN = 0.000
AVG = 0.000

JOHNSON SPACE CENTER
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Figure 3.2.3.2-16 Flex Mode Within Control System Passband

MODE NO. 11
FREQUENCY = 0.43 HZ



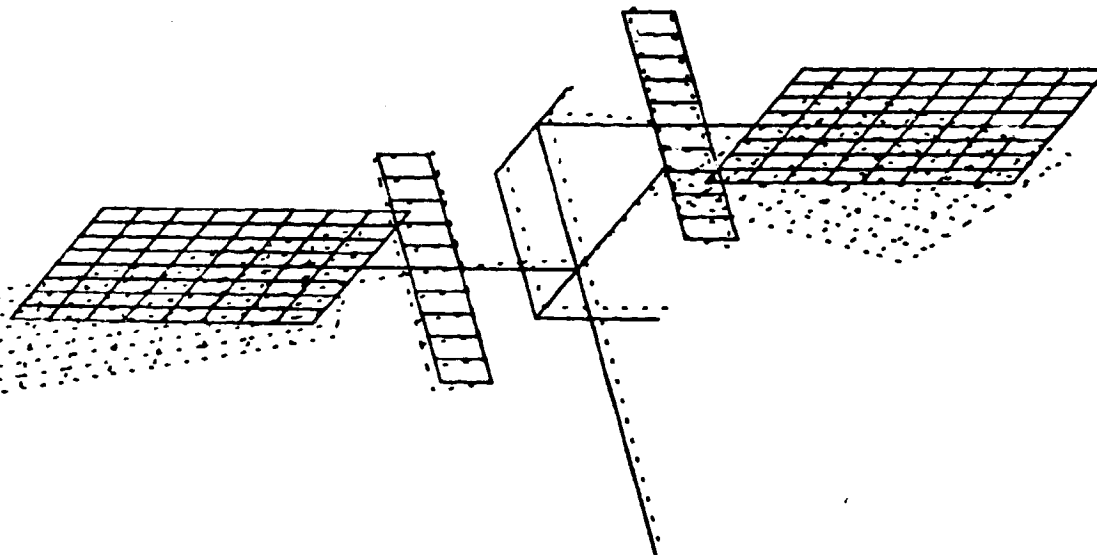
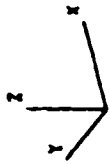
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ALPHA = -0.0002
BETA = 0.0002
GAMMA = 0.0002

Figure 3.2.3.2-17 Flex Mode Within Control System Passband

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STRUCTURAL MECHANICS BRANCH
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MODE NO. 8
FREQUENCY - 0.08 HZ



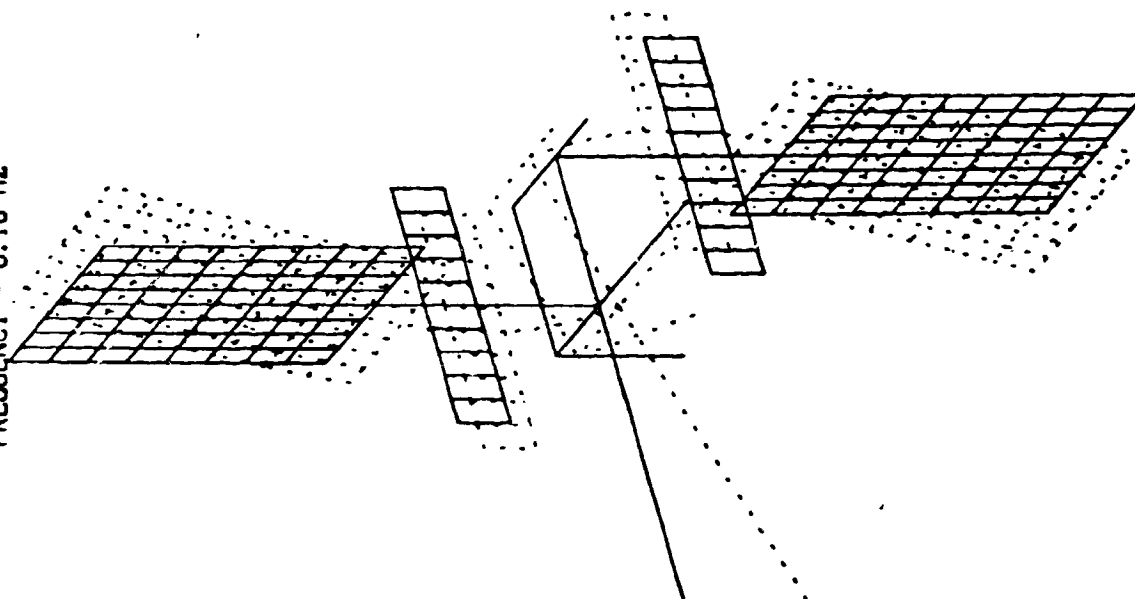
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RECT - 10.0 000.
CUBE - 10.0 000.

Figure 3.2.3.2-18 Flex Mode Within Control System Passband

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STRUCTURAL MECHANICS DIVISION
ESJ 12/12/83 JER

MODE NO. 9
FREQUENCY - 0.18 HZ



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PLATE : -80.0 000
SCALE : 80.0 000
SHEET : 30.0 000

Figure 3.2.3.2-19 Flex Mode Within Control System Passband

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(experimental Orbiter autopilot), and the frequency shaping autopilot are among the most attractive solutions.

The structural dynamics of the BB configuration during intermediate buildup stages was not analyzed at this time. The various stages will produce significantly different results from the analysis of the completed version. Depending on the buildup scenario of the BB configuration, the dynamics of this configuration will change throughout construction and be dramatically influenced by future module placements.

3.2.3.2.11 Summary of On-Orbit Flight Dynamics

The flight dynamics of the BB configuration has been studied in detail for the earth fixed (LVLH) attitude hold. Using mass and TEA trim objectives the momentum accumulation can be reduced to zero. Propellant resupply weight of up to 3,000 pounds for orbit maintenance does not seem to be a critical item.

3.2.3.3 Communications and Tracking Evaluation

The communication subsystem consists of hardware required to establish communication links between the Space Station and various vehicles. Antenna requirements for the subsystem are essentially the sum total of those requirements developed by considering each link separately. In this subsection, we will develop antenna specifications for the Building Block configuration by sequentially describing each operating link. Information on RF coverage, number of required antennas, type, makeup, and size of these antennas, and their estimated locations on the Space Station structure are given. Also, the ease of procurement or development of such antennas is discussed. The antenna design selected for this configuration to meet each required link coverage was based on studies that have been done to date. further study and evaluation could dictate alternative options that might be more advantageous based on numbers of antennas required and development risks. A summary of the antenna requirements for the building block configuration is given in table 3.2.3.3-1. The antenna locations for the IOC and growth Building Block configuration is shown in figures 2.2-1 and 2.2-2.

a. Space Shuttle Orbiter (SSO) link - This is an S-band link that supports two-way communication between the Space Station and the Space Shuttle Orbiter. Only one SSO is supported in IOC and two SSO's are supported in the growth version. The coverage required is limited to the hemisphere below the Space Station and extends to about 50 km in most directions except in a small sector directly behind the Space Station where it extends all the way to 2000 km.

Table 3.2.3.3-1

Antenna Requirements for the Building Block Configuration

<u>Communication Link</u>	<u>Antenna Type</u>	<u>Number of Antennas</u>	
		<u>IOC</u>	<u>Growth</u>
Space Shuttle Orbiter	S-band medium gain phased array	1	1
Multiple access link	K-band high gain multibeam phased array	2	2
	K-band medium gain multibeam phased array	1	1
Tracking and Data Relay Satellite	S/Ku-band dual feed dual frequency steerable parabolic reflector	1	1
Global Positioning System	L-band widebeam omni	1	1
Television	K-band high gain single beam phased array	2	10
Orbital Transfer Vehicle	K-band medium gain multibeam phased array	0	2
Space Shuttle Orbiter Rendezvous Radar	Omni directional	2	2
Rendezvous	Parabolic Reflector monopulse feed	2	2
Multiple Tracking	High gain phased array	0	2
	Medium gain phased array	0	2

The link is to be served with one medium gain (30 dB) phased array antenna made up of about 500 elements and measuring about 10 feet in diameter. The optimum location for such an antenna is somewhere on the bottom portion of the Space Station in such a way that the lower hemisphere is visible and unobstructed by Space Station structure elements. One choice would be a semi-spherical conformal array mounted on the right solar array boom.

Procurement of this antenna represents routine design and development effort if the array is passive (electronics separate from antenna elements). However, some risk is introduced in the development if the array is active with monolithic design (electronics combined with the antenna elements in one package).

b. Multiple access (MA) link - This is a K-band UNK that supports two-way communication between the Space Station and the EMU, FF, and OMV vehicles. The coverage is divided into two parts. The far range (to 2000 km) coverage is a 20° conical sector centered about the velocity vector in the forward and aft directions. For short range, the coverage is 4π - steradians to about 400 km.

Two high gain (41 dB) multi-beam phased array antennas made up of about 16,000 elements and measuring about 28 inches in diameter each will serve the far range sectors. These antennas must be mounted on the Space Station in such a way that their broadside direction is along the flight path. On this configuration, they are located one on the side of the habitat module and the other on the side of the lab module.

The above specification for the two high gain antennas assumed an operating frequency in the Ka - band at about 28 GHz. There will be some amount of risk associated with the development of such a large array antenna (16,000 elements) in the passive mode. The risk becomes high if the array

design is active and monolithic. The design difficulty can be reduced considerably by moving to a lower frequency like Ku-band where an array size of about 1,000 elements will be sufficient due to lower antenna gain (30 dB) and higher antenna efficiency.

An additional conformal antenna is needed to complete the spherical coverage required for short range. This antenna is a medium gain (27 DB at Ka-band) multibeam phased array made up of 1100 elements. It has an omnidirectional pattern in the elevation plane and mounts as a wrap-around the left solar panel boom.

Procurement of the latter antenna represents routine development effort if the array is passive and minimal risk if the array is active and monolithic irrespective of whether the design frequency is in the Ka or Ku bands.

c. Tracking and Data Relay Satellite (TDRS) link - This is a dual S/Ku-band link that supports two-way communication between the Space Station and the TDRS satellite. The coverage required is hemispherical in the elevation plane and forms an 80° sector in the azimuth plane.

The link is to be served with a dual-feed, dual-frequency mechanically steerable parabolic reflector of nine feet diameter. This antenna must be located on the topside of the Space Station in such a way that the upper hemisphere is visible. On this configuration, it is located on the right solar panel boom.

Procurement of this antenna is subject to a medium level of risk arising from the adaptation of the two feed systems to the mechanically steerable parabolic reflector.

(4)

d. TV links to FF's and OMV's - These are independent Ku-band links relaying digital TV signals from the FF's and OMV's back to the Space Station. Two links are needed in the IOC stage increasing to six links in the growth stage. The coverage on each link will be a 20° cone out to 2,000 km for far range coverage and a hemisphere below the station extending 50 km.

Each link can best be served by high gain conformal phased arrays to obtain a spherical coverage with minimum number of antennas. Each array will have a diameter of about four feet. On this configuration, one spherically conformal array per link would be used in IOC and mounted on the solar panel boom while in growth a new link would require two arrays with one mounted on the top user module and the other on the bottom user module.

The antenna arrays for the TV links represent high risk development items due to the large number of elements that would be involved in the design.

e. Orbital Transfer Vehicle (OTV) link - This is a K-band link supporting two-way communication with the OTV vehicle in the growth configuration only. The coverage is a full sphere with a maximum radius of 100 km.

The link can be served by a pair of medium gain phased array antennas each covering one hemisphere. The size of each array is 400 elements at Ka-band frequency and measures about five inches in diameter. The placement of these antennas on the Space Station is as follows: one antenna is located on the top surrogate payload bay and the other on the bottom surrogate payload bay.

The development of the array pair presents no risk if the array is passive. Minimum risk results if the array is active.

f. Tracking Links

Four links will be used to provide Space Station position and attitude information, and to provide relative position and velocity information on other Space Colony vehicles and objects within specified volumes of concern. The Global Positioning System (GPS) Satellite Constellation Link is an L-band receive-only navigation and tracking link. The Space Station GPS antenna must be able to receive code tracking information from a group of four satellites simultaneously. The antenna coverage consists of a 160° cone centered about the Space Station local vertical.

The link would be satisfactorily served by a low gain omnidirectional antenna. This antenna must be mounted on the Space Station in such a way that most of the upper hemisphere is clearly visible. On this configuration, it is mounted on the left solar panel boom.

Procurement of such an antenna is routine, and there is no development risk involved.

A Shuttle Rendezvous Radar link will be completed by a transponder onboard the Space Station. Two transponders and two omnidirectional antennas will be used for this link.

Rendezvous radar links will be used to maintain continuous position and velocity data on vehicles that are approaching the Space Station during the implementation of flight plans which involve docking. Similar position and velocity data will be provided for vehicles that are departing, and are within a specified range of concern. Two antennas, directed fore and aft along the velocity vector, will be used for this function; each antenna is expected to be approximately three feet in diameter.

Multiple vehicle tracking will be accomplished by Search and Track Radars which will maintain updated position information on vehicles at

distances as great as 2,000 km. A minimum of two antennas will be used for this purpose, to provide coverage of the fore and aft directions along the velocity vector. A maximum of four antennas will be used to provide complete coverage of a specified volume around the Space Station.

3.2.3.4 Elements/Utilities Interfaces and Mechanisms

3.2.3.4.1 General

All major elements of the building block concept are assembled using the standard berthing interface. Solar arrays and primary radiator elements are mounted on a large boom which is joined to the station through a standard berthing interface. The boom incorporates two rotary joints which provide full 360° rotation about the boom axis and + 52° pivoting perpendicular to the boom axis. Electrical power and thermal control fluid and vapor loops must cross these rotary joints.

3.2.3.4.2 Berthing Mechanism

Berthing involves use of a manipulator to achieve final closure of two spacecraft or assembly elements, thereby insuring relatively small misalignments and contact velocities. Contact energy attenuation requirements are low and alignment guides are shorter than would be required for docking operations. The berthing interface comprises alignment guides, structural latches, a telescoping pressure tunnel, retract/extend actuators, utilities interconnect provisions and supporting structure (see figure 3.2.3.4-1). Four alignment guides are incorporated to provide 90° indexing for station elements. Guide length of 5.75" will accommodate expected misalignments for berthing operations. The manipulator, aided by the alignment guides and other

sensors as required, brings the interfaces within the envelope of the combined capture/structural latches. Operation of these eight latches, located on the

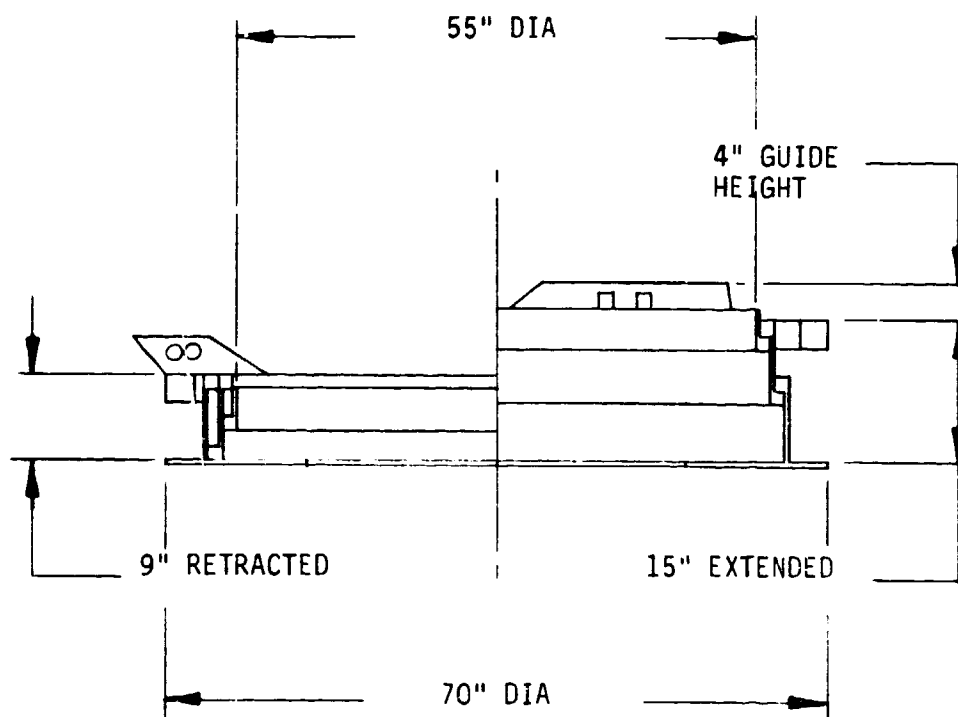
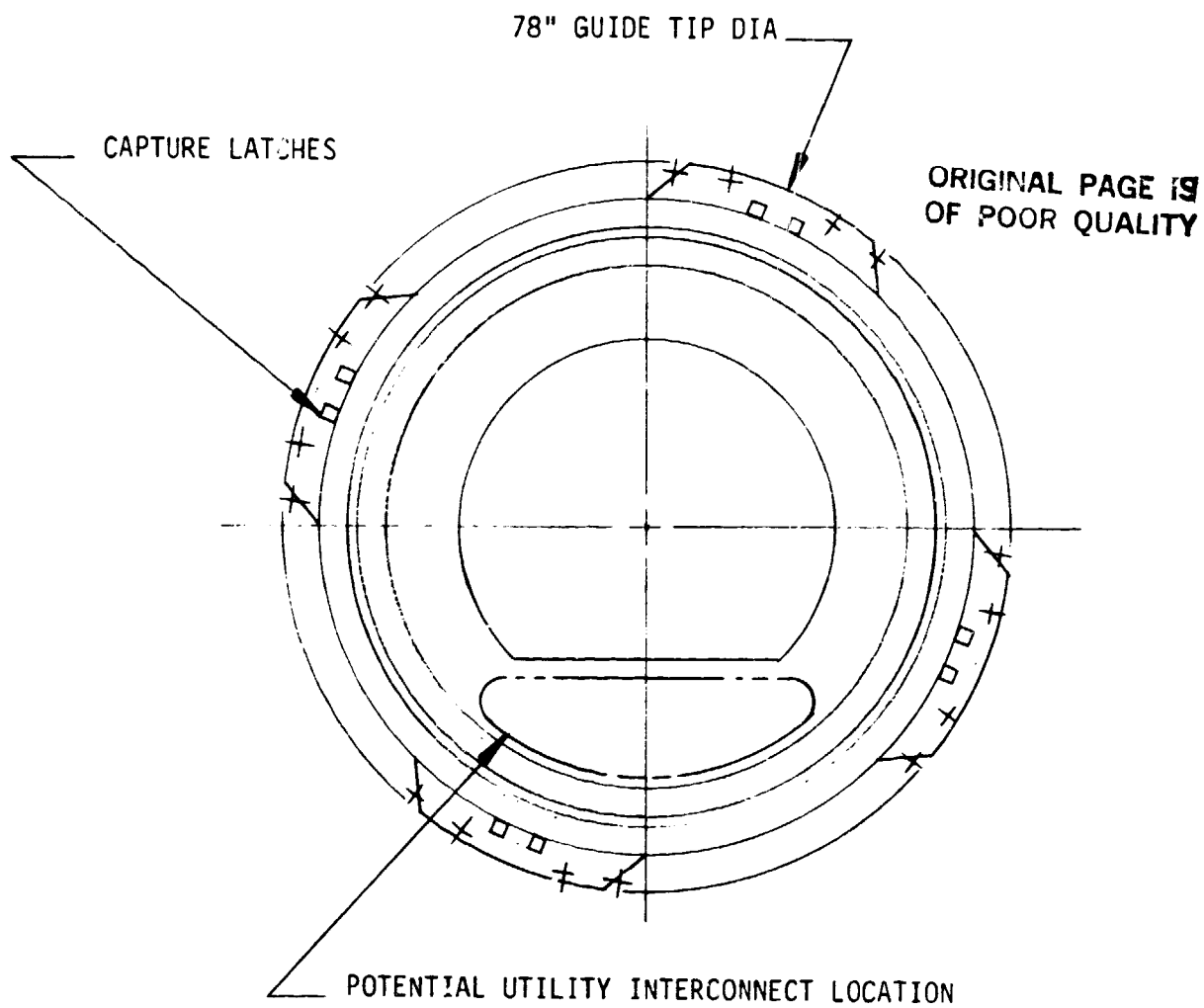


FIGURE 3.2.3.4-1 FOUR GUIDE BERTHING INTERFACE

alignment guides, completes the structural mating of the interface. The structural latches are sized to carry the full pressure load and all dynamically induced loads across the interface. Within the 15" length of the berthing mechanism, a six inch stroke of the mating interface will be provided by three pairs of electromechanical actuators. After structural mating is accomplished, these actuators will be fully extended.

The telescoping pressure tunnel, shown in figure 3.2.3.4-2, is extended by independent small electromechanical actuators. The tunnel concept incorporates redundant pressure seals and a complete set of tunnel elements may be extended from either side of the interface.

Several concepts for utilities interconnects have been proposed. The concept most favored is to accomplish manual connection of all safe utilities within the pressurized environment using provided jumper hardware. Connection of thermal control freon loops must be executed outside the habitable volume. Automatic extension and connection of thermal control fluid and vapor lines either through openings in the alignment guides or outside the alignment guides appears feasible but design has not been accomplished. The size and type of utilities interconnects which must cross the berthing interface between modules are shown in table 3.2.3.4-1. Other than the freon lines, all connections will be within the pressurized environment.

Unberthing is accomplished by disconnecting utilities, withdrawing the pressure tunnel, and releasing the structural latches. If the element is attached at both ends, all involved berthing interfaces may be retracted, providing one foot clearance on each end for lateral removal. It may be necessary to provide temporary interconnects for some utilities, notably thermal control, if an element is removed for a significant time.

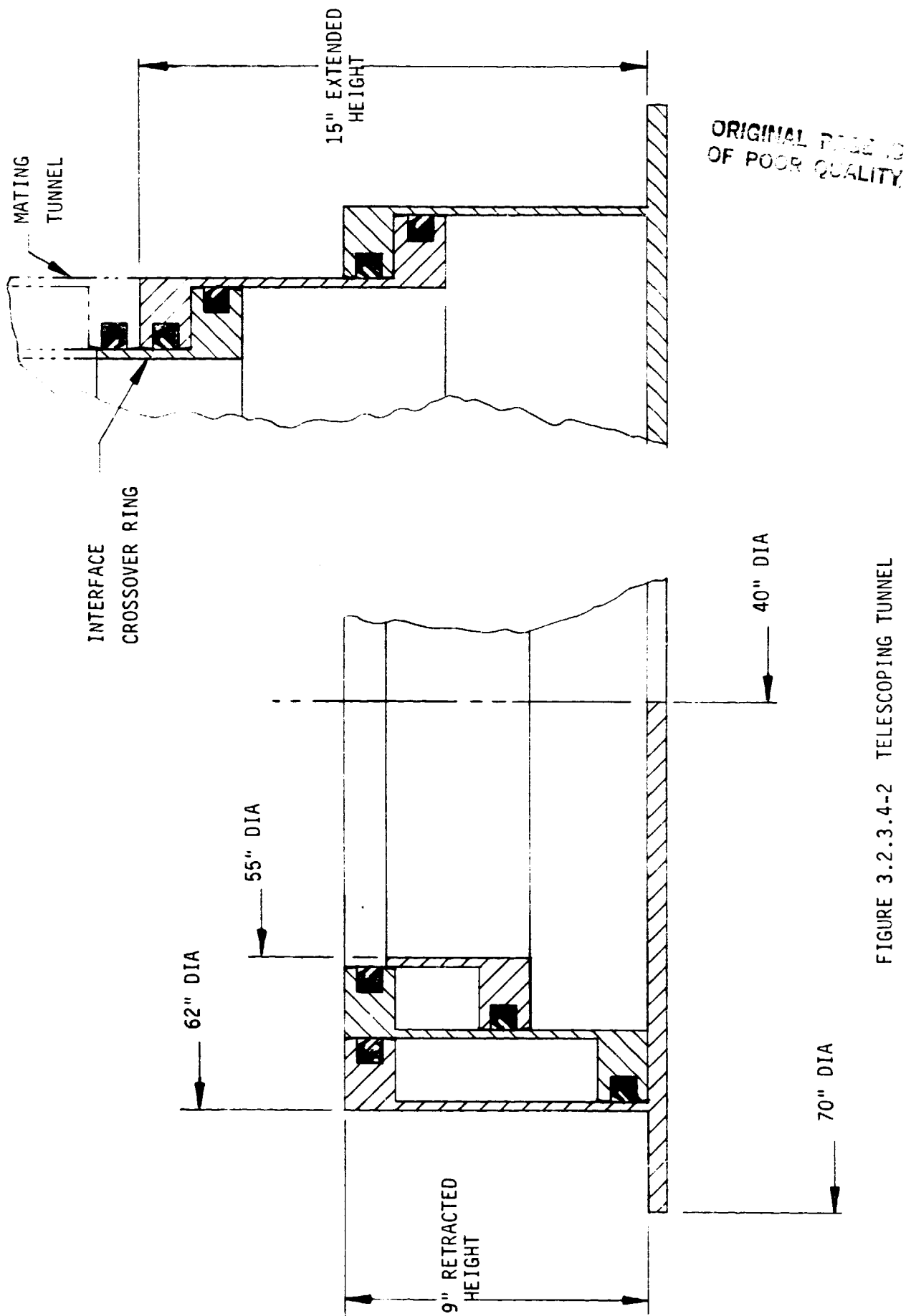


FIGURE 3.2.3.4-2 TELESCOPING TUNNEL

NAME	NO.	TYPE	COMMODITY	QUANTITY	UNITS	SIZE	MATERIAL
FREON SUPPLY	1	H. PRESS. LIQ.	FREON	2500	LB/HR	1" ID. TUBE	S. STEEL
FREON RETURN	1	L. PRESS. BI-PH.	FREON	2500	LB/HR	2" ID. TUBE	S. STEEL
COOLANT SUPPLY	1	L. PRESS. LIQ.	WATER	500	LB/HR	3/4" ID. TUBE	S. STEEL
COOLANT RETURN	1	L. PRESS. LIQ.	WATER	500	LB/HR	3/4" ID. TUBE	S. STEEL
DRINKING WATER	1	L. PRESS. LIQ.	WATER	50	LB/DAY	.5" ID. TUBE	S. STEEL
WASTE WATER	1	L. PRESS. LIQ.	URINE/FLUSH	100	LB/DAY	.5" ID. TUBE	S. STEEL
OXYGEN SUPPLY	1	MED. PRESS. GAS	OXYGEN	20	LB/DAY	3/8" ID. TUBE	S. STEEL
NITROGEN SUPPLY	1	MED. PRESS. GAS	NITROGEN	5	LB/DAY	1/4" ID. TUBE	S. STEEL
WASTE WATER	1	L. PRESS. LIQ.	CONDENSATE	3	LB/HR	1/2" ID. TUBE	S. STEEL
WASH WATER	1	MED. PRESS. LIQ.	GRAY WATER	150	LB/DAY	1/2" ID. TUBE	S. STEEL
AIR SUPPLY	1	LOW PRESS. GAS	AIR	150	CFM	4" ID. TUBE	COMPOSITE
DATA ACQ/TLM	4	MULT. COND. CABLE	DIGITAL DATA	--	--	40 WIRE CONN.	-----
T,C&N CNTRL/STATUS	4	MULT. COND. CABLE	DIGITAL DATA	--	--	8 WIRE CONN.	-----
AUDIO CONTROL	2	FIBER OPTIC	DIGITAL DATA	--	--	1/2" DIA. CONN.	-----
AUDIO SIGNAL	2	FIBER OPTIC	DIGITAL DATA	--	--	1/2" DIA. CONN.	-----
REGIONAL DATA BUS	4	FIBER OPTIC	DIGITAL DATA	--	--	1/2" DIA. CONN.	-----
POWER. DIST. CNTRL BUS	4	FIBER OPTIC	DIGITAL DATA	--	--	1/2" DIA. CONN.	-----
POWER SUPPLY	4	INDUCTIVE	HIGH VOLT. AC	25	KW	6" DIA. CONEPAIR	-----
MISC. DATA BUS	8	FIBER OPTIC	DIGITAL DATA	--	--	1/2" DIA. CONN.	-----

TABLE 3.2.3.4-1 INTERMODULE UTILITIES INTERFACES

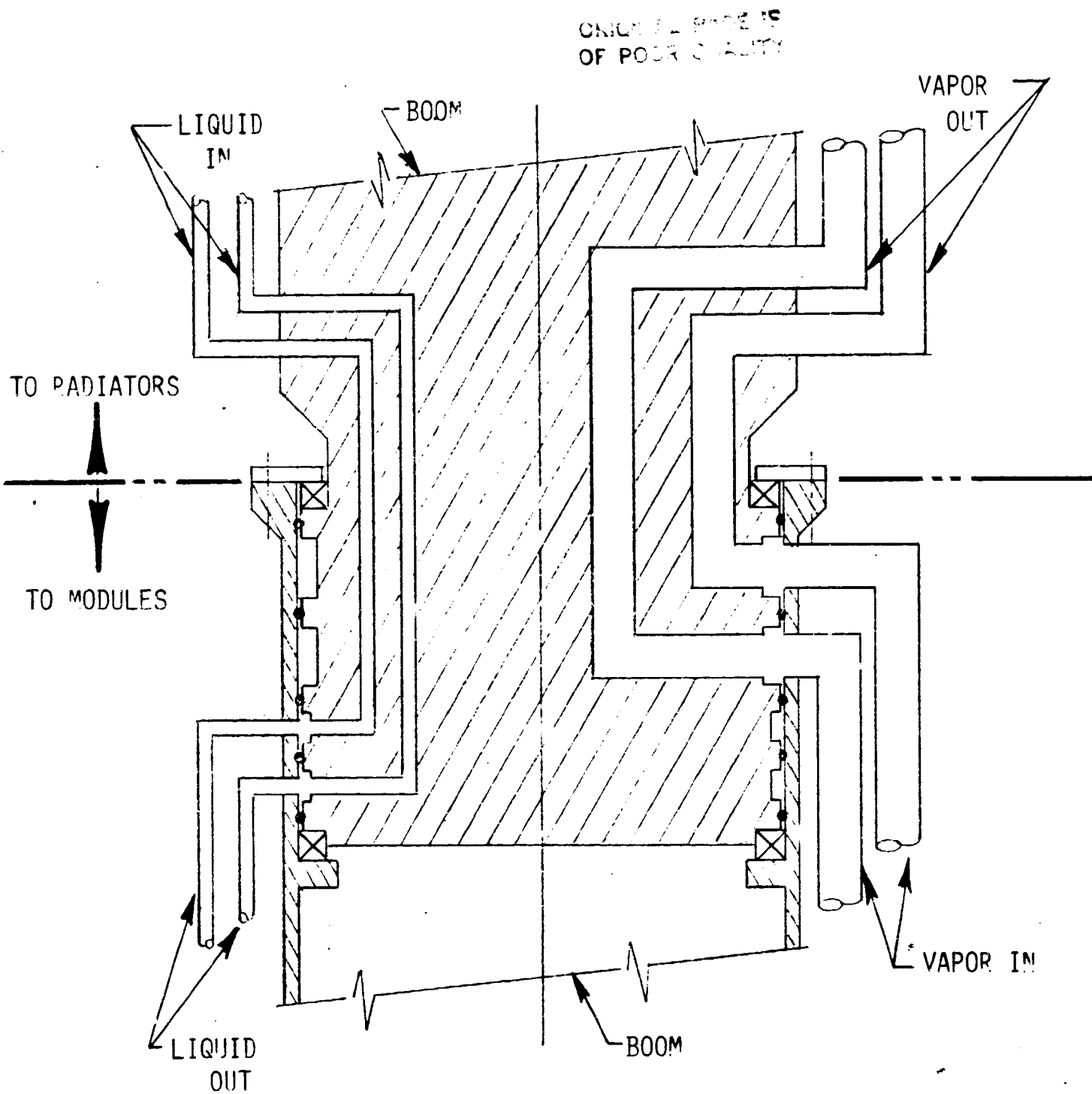
3.2.3.4.3 Boom Mechanisms

The large booms which support the solar arrays and major radiator elements are attached to the station proper through the standard berthing interface. To achieve optimum orientation, solar arrays and radiators are mounted outboard of rotary joints which provide two degrees-of-freedom relative to other station elements. The power storage and conditioning modules are also mounted outboard so that only AC power and freon liquid and vapor lines must be brought across the rotary joint interfaces.

The inboard joint provides $\pm 52^\circ$ pivoting perpendicular to the boom axis. Flexible couplings should be adequate for both electrical power and thermal control system transfers. The outboard joint provides 360° rotation about the boom axis. As this joint will be nonreversing, it is necessary to transfer utilities through the drive mechanism itself. Electric power will be transferred through inductive coupling of coils built into rotating and stationary parts of the mechanism. A conceptual sketch showing transfer of fluids through the rotary joint may be seen in figure 3.2.3.4-3. The inductive coupling and mechanical drive elements are not shown for clarity. Detailed design of the mechanical and electrical power transfer concepts has not been accomplished. Both should be somewhat more straightforward than the fluid transfer.

3.2.3.4.4 Station Wiring Concept

Figure 3.2.3.4-4 illustrates a wiring concept for power distribution from the boom mounted solar arrays to the various elements of the building block configuration. DC power is delivered from the solar arrays to the Power Conditioning Modules (PCM) through two pairs of #2 wire with two pin connectors at each end as shown. The power is converted at this point to three phase 400 VAC and routed from the PCM to a rotary transformer contained



(ROTARY TRANSFORMERS INCLUDED
IN THIS JOINT ARE NOT SHOWN)

Figure 3.2.3.4-3. Rotary Fluid Joint Schematic
Building Block Configuration

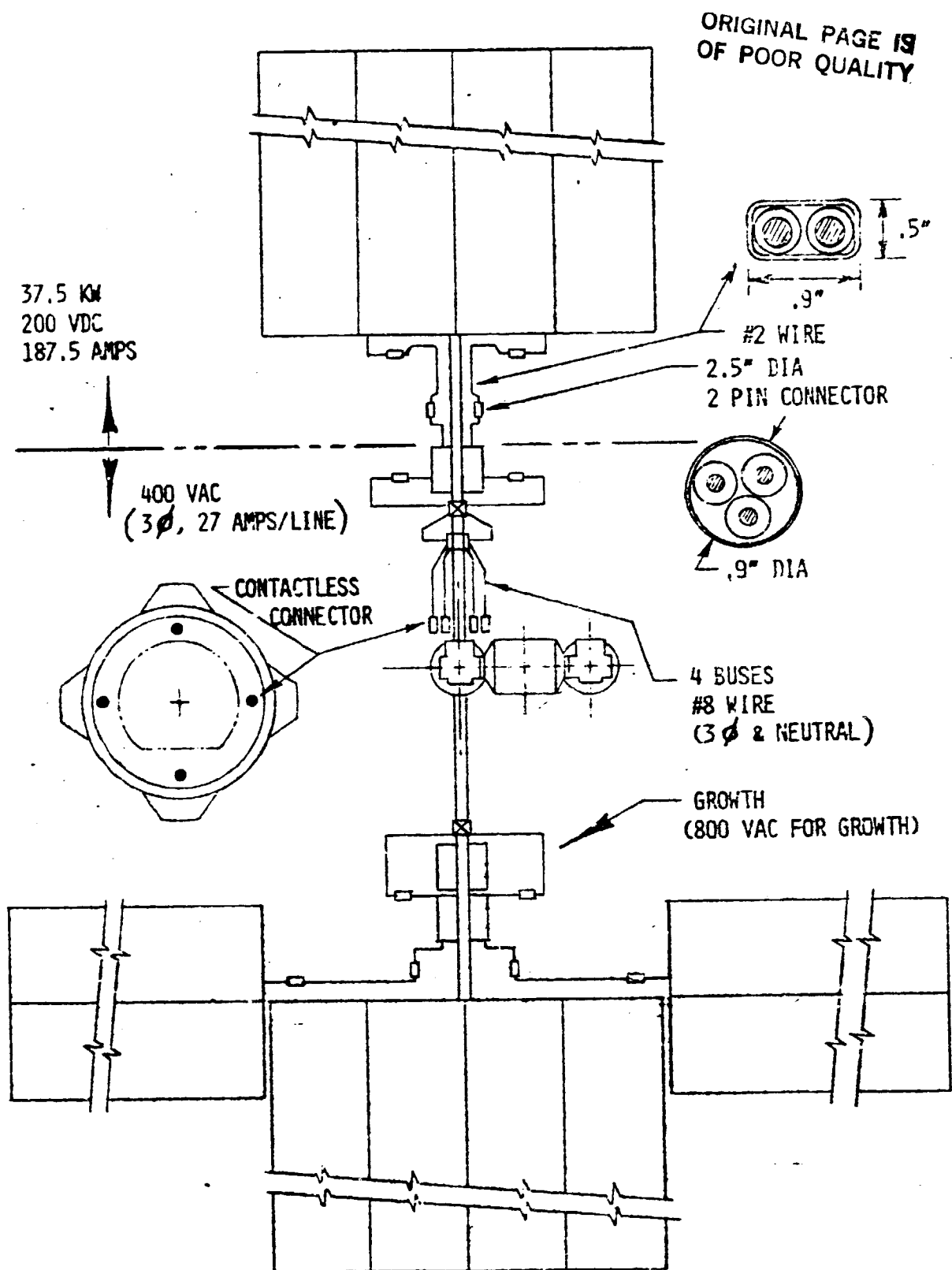


Figure 3.2.3.4-4. Power Distribution Concept-Building Block Configuration

within the boom rotary joint. Out of the rotary transformer, power goes to a distribution switching box which provides four distribution busses. The four distribution busses are routed through contactless connectors in the standard berthing interface, to all modules and elements requiring power. Adjacent modules may be disconnected or a module may be removed without interrupting power to the remaining modules. Two distribution busses serve as supply busses at any time. Redundancy is provided by switching to the other pair of distribution busses at the distribution switching box. For growth, similar connections are made and voltage is increased from 400 VAC to 800 VAC to avoid an increase in wire size.

3.2.3.4.5 Thermal Transport Concept

Figure 3.2.3.4-5 illustrates a plumbing concept for a redundant thermal bus system which services the various modules. Liquid and vapor busses are precharged and come up attached to the exterior of the module structure. After the modules are joined at the berthing interface, the thermal busses must be connected. Automatic connection is preferred but verification of connections may require either EVA or sophisticated verification systems. The building block configuration tends to accommodate this type of series connection. If a module is to be removed without interrupting service to the remaining modules, a bypass system must be installed as is indicated for the liquid bus. A bypass would also be required for one of the vapor busses.

3.2.3.4.6 Manipulator Systems

The Space Station manipulator will be the standard Orbiter RMS unless further evaluation of the assembly process establishes the need for greater reach capability. The RMS shoulder will be mounted to a berthing interface mechanism modified to accommodate RMS power and control utilities only.

BY-PASS SYSTEM
ASSEMBLED WHEN
REQUIRED FOR MODULE
REPLACEMENT

PUMP ASSY.

LIQ TO LIQ
HEAT EXC.

OR
OF POOR QUALITY

LIQ BUS "B"

LIQ BUS "A"

VAP BUS "B"

VAP BUS "A"

Figure 3.2.3.4-5. Thermal Connections Typical
Arrangement for Building Block
Configuration

Through the berthing interface, the manipulator may be stationed at any available berthing port.

The growth configuration will add two additional manipulator systems identical to the first.

3.2.3.4.7 Hangar and Satellite Servicing Mechanisms

The OMV and OTV hangars and the satellite servicing facility will be attached to the station using the standard berthing interface. Each of these facilities will include simple beam structures representative of the Orbiter PLB longerons and keel. Lightweight Orbiter payload retention fittings will be provided to mate with already present trunnions on the OMV, OTV, and large satellite elements.

Utilities will be brought to the service/storage facilities through the berthing interface, as for modules.

The OMV and OTV hangar doors will be provided with conventional hinge, latch and drive mechanisms. The satellite servicing facility does not include doors.

3.2.3.5 Thermal Control - Evaluation

3.2.3.5.1 Introduction

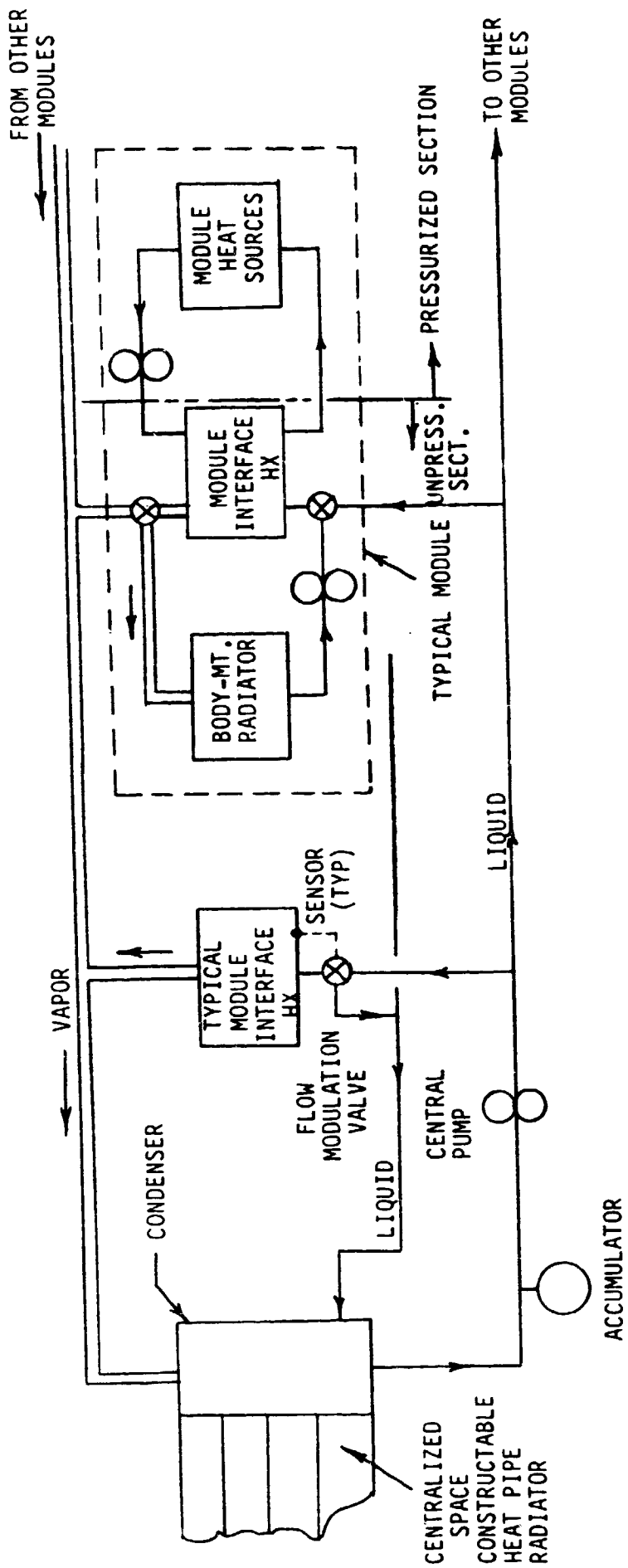
Engineering evaluation considerations during this study were:

- o Vehicle thermal environment (i.e. view factors, blockage, heat fluxes)
- o Radiator area requirements
- o Orbiter impacts
- o Design complexity
- o Verification complexity
- o Surface contamination sensitivity
- o Hardware commonality
- o Technology status

The following discussions will present a system overview and will assess how well the SOC vehicle configuration satisfies these factors.

3.2.3.5.2 System Overview

The candidate Active Thermal Control Subsystem (ATCS), schematically illustrated by Figure 3.2.3.5-1, is a hybrid design concept that maximizes the use of local thermal control for individual station modules and satisfies the remaining thermal control requirements with a centralized system. Each station module will contain a heat collection and transport system similar in function to the Shuttle Orbiter cabin design (i.e., a pumping system, cold-plates, heat exchangers, plumbing lines and flow control valves). These individual station module systems will be integrated with a central transport system. In addition, each station module will have heat pipe space radiators (operating at about 70°F) integrated with the module meteoroid protection shield. The size of these radiators will vary from module to module depending on surface area availability considering docking ports, windows, thermal blockage, etc.



ORIGINAL DRAWING
OF POOR QUALITY

Figure 3.2.3.5-1. Active Thermal Control Subsystem Concept

When waste heat in a station module exceeds its thermal capacity, the excess heat will be transferred to a central collection and transport circuit for delivery to a central deployed radiator attached to the solar array boom. Also, a separate high temperature radiator (operating at about 160°F) will be attached to the solar array boom to reject electrical power system waste heat from the regenerative fuel cells and electrolysis units. Because the central transport circuit (or "thermal bus") uses a two-phase working fluid that transfers heat by evaporation and condensation rather than by sensible heat changes of a single phase coolant, it operates at a constant temperature over the entire length of the loop. Furthermore, this "thermal bus" is capable of transporting large thermal loads over long distances with pumping requirements that are very small compared to single phase fluid systems. Table 3.2.3.5-1 summarizes the IOC weight and power estimates for the candidate ATCS concept. A vehicle thermal system design which judiciously applies thermal coatings, vacuum type insulations, isolators, and heaters will be selected for those systems and elements which are not integrated into the ATCS. The system will be selected to minimize the addition of electrical heat for thermal control purposes. The systems which appear to require such a design at this time, are the communications (antennas), propulsion, remote manipulator, and control moment gyros. Heaters in these systems will eliminate thermostats and their inherent failure modes by using sensors to feed software logic for heater control.

An insulation/coating system will be selected for the habitable areas and power generation systems which complements the active heat rejection systems. Insulations and coatings will be applied to unpressurized areas such as the satellite service structure and OMV and OTV hangars in order to bound the thermal environments within the payloads design envelopes, while minimizing

Table 3.2.3.5-1. IOC Active Thermal Control
Subsystem Characteristics

STATION ELEMENT	WEIGHT (LBS)		POWER (KW)
	DRY	WET	
C/C ₁	1,345	1,465	0.33
C/C ₂	1,345	1,465	0.33
LAB ₁	2,621	2,945	0.89
LAB ₂	1,803	2,002	0.52
HAB ₁	2,452	2,591	0.33
LOG ₁	485	514	0.06
SOLAR ARRAY BOOM	6,683	6,943	0.51
TOTAL	16,734	17,925	2.97

operation of the payload thermal/control systems and station power requirements.

Virtually all elements of the BB configuration receive direct solar energy and will require surface treatments with low solar absorption to emissivity ratios to limit structural temperatures and heat leak into the element. This requires the application of paints and films since this cannot be achieved with treated metal surfaces. Surface property degradation is discussed in section 4.2.2.3.

A lightweight high performance multi-layer insulation system of up to 20 layers, approximately 0.25 pounds per square foot, similar to that of the Shuttle Orbiter, is envisioned. The insulation weights for the BB-IOC and growth versions are 4,119 and 10,800 pounds, respectively.

Local protection from RCS engines plume heating will be required. The extent of the protection and its impact on design will depend on engine firing requirements.

The propellant tanks of the monopropellant hydrazine propulsion system will be individually mounted on the command module and each will be maintained within temperature limits through passive thermal control. For the hot environment, each tank (3.5 foot diameter) will be maintained below its upper temperature limit by use of insulation and an appropriate coating. For the cold environment, each tank and the fuel distribution system will be maintained above its lower limit by the use of insulation and heaters. The heater wattage needed for this purpose is shown in table 3.2.3.5-2.

Preliminary design indicates that the 25 pound thrusters will be placed in clusters of 12 thrusters each and will be mounted on the command module next to the propellant tanks. Passive thermal control of the thrusters and their feedlines will be achieved through insulation of the cluster and the use of

heaters for the engines and lines. Heater wattage needed is shown in table 3.2.3.5-2.

The thermal control heaters for the propulsion system are sized based on a 50% duty cycle.

TABLE 3.2.3.5-2
PROPULSION SYSTEM HEATER REQUIREMENTS

CONFIGURATION	TANKS & FUEL DISTRIBUTION			THRUSTERS & FEEDLINES	
	# TANKS	TOTAL AREA FT	HEATERS WATTS	# THRUSTERS	HEATERS WATTS
BB - IOC	8	308	862	24	960
BB - GROWTH	16	616	1724	24	960

The passive thermal control design of the antennas is similar to that of the Orbiter Ku-band antenna. Each electronics box will be of minimal thickness with the electronics mounted directly to a cold plate radiator located on the large face of the box. The box will be covered with silvered teflon with an absorptance/emittance (α/ϵ) = .13/.8. The radiator area for each electronic box and internal heat generation for each different type of antenna is shown in table 3.2.3.5.-3. Also shown in this table is the heater wattage needed in each electronic package to keep the electronics above their minimum temperature.

The heater wattage needed to maintain the gyros, gimbals, and comparator of the S/Ku-band steerable dishes above their minimum temperatures are shown also in table 3.2.3.5-3. The heaters for maintaining minimum temperatures are sized based on a 50% duty cycle. Antenna heater operation will only occur when the antenna is off two hours or more.

TABLE 3.2.3.5-3
IOC BUILDING BLOCK ANTENNA THERMAL CHARACTERISTICS

ANTENNA TYPE	NO	ELECTRONICS PACKAGE FOR EACH ANTENNA				TOTAL THER. CONT. HEATERS WATTS	ANTENNA COMPONENTS	
		TEMP LIMITS F°	INT. HEAT GEN. WATTS	RADIATOR AREA FT ²	THERMAL CONT. HTRS* WATTS		EACH ANTENNA WATTS	TOTAL WATTS
S-BAND MED GAIN P.A.	1	32-131	335	11.2	525	525	---	---
K-BAND HIGH GAIN MULTI P.A.	2	32-131	250	8.4	394	788	---	---
K-BAND MED GAIN P.A.	1	32-131	175	5.9	277	277	---	---
S/KU-BANDS STEERABLE DISH	1	130-152	250	8.4	394	394	230	230
L-BAND WIDE BEAM	1	0-191	45	1.5	70	45	---	---
K-BAND HIGH GAIN P.A.	2	32-131	85	2.8	131	262	---	---
TOTAL						2,014		230

GROWTH BUILDING BLOCK ANTENNA THERMAL CHARACTERISTICS

S-BAND MED GAIN P.A.	1	32-131	335	11.2	525	525	---	---
K-BAND HIGH GAIN MULTI P.A.	2	32-131	250	8.4	394	788	---	---
K-BAND MED GAIN P.A.	3	32-131	275	5.9	277	831	---	---
S/KU-BANDS STEERABLE DISH	1	130-152	250	8.4	394	394	230	230
L-BAND WIDE BEAM	1	0-191	45	1.5	70	70	---	---
K-BAND HIGH GAIN P.A.	10	32-131	85	2.8	131	1131	---	---
TOTAL						3,739		230

* HEATERS SIZED FOR 50% DUTY CYCLE

3.2.3.5.3 Technical Evaluation

3.2.3.5.3.1 Thermal Environment

The BB configuration Space Station configuration orbits in a gravity gradient stabilized, earth-oriented attitude. This results in constant terrestrial thermal fluxes incident on the structural elements with somewhat cyclical solar and albedo incident energies.

Various segments of the module surfaces will be sunlit throughout the day portion of the orbit with increasing areas being sunlit with higher beta angles. It has been proposed that essentially all of the module surface (except for windows and external equipment) be covered by body-mounted radiators in order to reduce the size of the deployed, planar radiators. Therefore, it is assumed that high performance (low (α/ϵ) ratio) thermal coatings will be required for all surfaces used to reject heat. These coatings should be refurbishable or replaceable with minimal operational impact.

In order to assess the worst case incident thermal flux levels, analysis was accomplished with the SOC configuration orbiting with a solar Beta angle of 52° . Orbital average incident flux levels are shown in figure 3.2.3.5.-2. As can be seen, solar and albedo fluxes are relatively high on the modules but are quite low on the deployed radiators. The low flux levels on the radiators occur because they are assumed to remain edge to the sun throughout the orbit. This presupposes that the booms on which the radiators are located will be rotated to maintain the inertial pointing capability of the solar arrays as well as providing for minimal incident thermal fluxes on the radiators. This rotation would then imply the utilization of a fluid swivel or slip ring through which the working fluid could transfer thermal energy.

[illegible]

Figure 3.2.3.5-2. SOC Configuration Orbital Average Thermal Fluxes; Beta=520

Space viewing factors are given in figure 3.2.3.5-3. These factors may appear somewhat low, but take into account the full module circumference instead of only a preferred segment for body-mounted radiator location. The deployed planar surface radiators are active on both sides so one side will have approximately 25% of its space viewing blocked by the station modules and structure with the other side having a somewhat better view.

If full surface body-mounted radiators are used on the modules, thermal interaction could be significant between radiators of different temperatures with good views of one another. This becomes more of a problem if the view to space is limited by other structure such as the hot sunlit solar arrays. All of these influences must be factored into an accurate assessment of radiator heat rejection capability.

The IOC and growth versions of the BB configuration will have quite different thermal characteristics. Some modules which have a good view to space at IOC will have that view reduced significantly by the addition of subsequent structural components. These reduced heat rejection capabilities at the modular level must be compensated for during the growth buildup phase. This would suggest that thermal load sharing between modules exist and/or that a greater load be assumed by the deployed radiators.

3.2.3.5.3.2 Radiator Areas

Radiator area requirements initially were defined for body-mounted radiators integrated with station module meteoroid protective shields to determine heat rejection capabilities from each station module. In general, the effectiveness of the body-mounted radiators is significantly reduced by blockage effects from surrounding vehicle elements as discussed in section 3.2.3.5.3-2. As a result, although most of the cylindrical station module walls are available, body-mounted radiators can only reject about 30-35% of

the station total waste heat as summarized in Table 3.2.3.5-4. Deployed radiator panels were sized to reject the balance of the vehicle waste heat not accommodated by the body-mounted radiators. In order to reduce orbit environment heat loads on these two-sided deployed panels and thus reduce area requirements, the radiators are mounted to the solar array boom to maintain an "edge-to-sun" attitude. For IOC, two-sided deployed radiators with a total radiating area of 5,346 ft² are required. This total includes 1,237 ft² of high temperature radiator (160°F average) to reject the electrical power system waste heat. The total two-sided deployed radiating area increases to 10,043 ft² for the growth station which includes 2,473 ft² for the power system. The aforementioned radiators were sized to reject the total vehicle waste heat load. Past studies have shown that the use of a thermal storage phase change material can further reduce area requirements when large temperature transients are encountered. These transients normally result from widely varying environmental heat fluxes and/or internally generated vehicle waste heat. For this study, the power system radiators were selected to illustrate the potential application of thermal storage.

Because of the difference in day/night times and the difference in efficiencies between the fuel cell modules and the electrolysis modules, the night time heat load for the power system is much greater than the day time heat load. As mentioned, if part of the night time heat can be stored in a phase change material for rejection during the day time, the power system radiator area can be reduced further. One candidate for a phase change thermal storage material for the regenerative fuel cell heat rejection system is Barium Hydroxide Octahydrate. Its density is 136 lb/ft³, melting point is 172°F, and latent heat is 129 btu/lb.

BODY-MOUNTED RADIATOR HEAT REJECTION CHARACTERISTICS*

TABLE 3.2.3.3.5-4

STATION ELEMENT	IOC			GROWTH		
	WASTE HEAT LOAD (KW)	REJECTION CAPABILITY (KW)	AVAILABLE AREA (FT ²)	WASTE HEAT LOAD (KW)	REJECTION CAPABILITY (KW)	AVAILABLE AREA (FT ²)
C/C1	4.9	5.0	580	10.1	5.0	580
C/C2	4.9	5.0	580	8.2	5.0	580
HAB1	8.6	18.0	1,451**	10.1	18.0	1,451
HAB2	----	----	----	8.5	18.0	1,451
LAB1	45.5	7.2	580	46.0	7.2	580
LAB2	24.5	7.2	580	25.0	7.2	580
LAB3	----	----	----	9.1	4.9	580
LAB4	----	----	----	9.1	4.9	580
LAB5	----	----	----			
LAB6	----	----	----	36.2	18.4	1,451**
LAB7	----	----	----	9.1	5.7	580
LAB8	----	----	----	9.1	5.7	580
TOTALS	88.4	42.4	3,771	180.2	100.0	8,993

* TOTAL VEHICLE WASTE HEAT LOADS: 137 KW (IOC)

(NEGLECTING COMM/TRACKING) 277 KW (GROWTH)

** LONG MODULE

Preliminary analysis shows that the use of 429 lb. of this phase change material would reduce the required remote radiator area by about 50%.* Required radiator area and capability and applied heating loads without and with thermal storage are shown in figures 3.2.3.5-4 and 3.2.3.5-5 respectively. Although the weight of the phase change material and associated hardware will probably be equivalent to the radiator weight reduction, other design considerations such as view factors and blockage may still favor the use of thermal storage material. In addition, a thermal storage approach permits a non-articulated radiator to be a viable station option.

(* Power system waste heat characteristics used in the thermal storage evaluation were not the same as used in the final radiator sizes documented earlier; however, the general conclusions reached and relative savings demonstrated are valid.)

3.2.3.5.3.3 Orbiter Thermal Control Impacts

While the Shuttle Orbiter is docked to the station, heat rejection from the Orbiter radiators is reduced about 15% due to blockage from surrounding station elements. This reduction is considered acceptable since the Orbiter probably will be powered down the majority of the time.

There are no additional Orbiter thermal control impacts that can be identified at this time.

3.2.3.5.3.4 Design Complexity

The primary design complexity involves the deployed radiator and its associated launch packaging boom/contact heat exchanger deployment radiator

SOC REMOTE F/C RADIATOR WITHOUT THERMAL STORAGE (752 FT²)

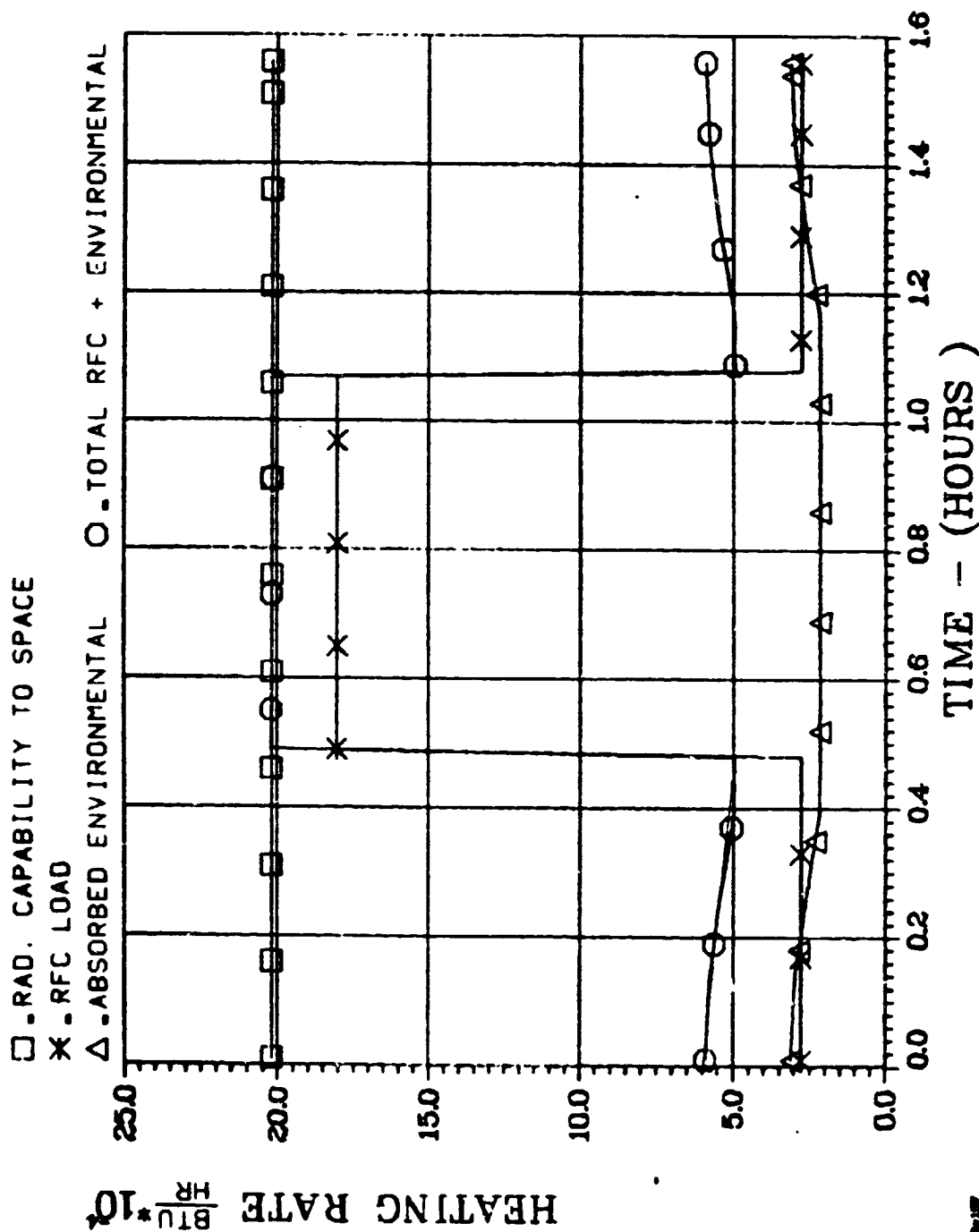


Figure 3.2.3.5-4

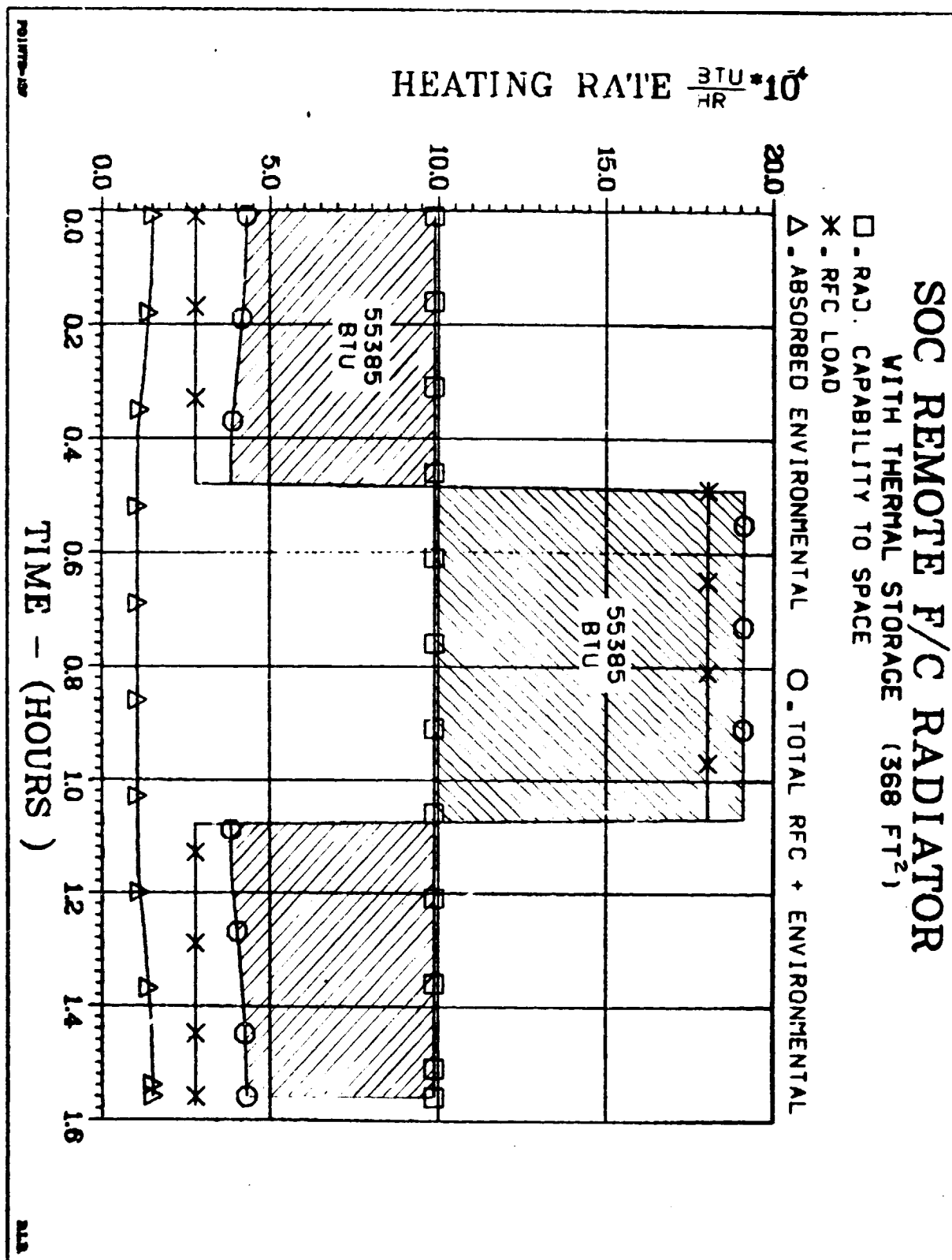


Figure 3.2.3.5-5

construction, and activation. Since it is desired to maintain an "edge-to-sun" attitude for the deployed radiator panels, a gimbal system will be required.

3.2.3.5.3.5 Verification Complexity

Component level verification should follow that of previous programs with the possible exception of life cycle tests. Items which fall into this category are insulations, coatings, heater system components, and fluid distribution system components. These tests with the possible exception of the heat pipe-based "thermal bus" and heat pipe radiators, do not appear to be any more complex than those of past programs.

The question of verification complexity in the thermal area arises from verification of the integrated thermal control design of the Space Station. The recommended approach is to baseline ground thermal testing of typical elements and interfaces based on design commonality (to the fullest extent possible) supplemented by Orbiter in-bay or deployed testing of items requiring unique environments such as heat pipe radiators. Testing during the Space Station buildup would be limited to checkout type tests.

Since the thermal verification approach is not highly configuration dependent, additional discussion is presented in section 4.2.2.7

3.2.3.5.3.6 Surface Contamination

A high probability of thermal control surface degradation exists as a result of the close proximity of RCS engines to station modules. Most surface treatments are expected to exhibit and require low solar absorptivities which will increase as a result of plume impingement.

The distance from RCS engines to radiators and solar panels should minimize

contamination of these surfaces. However, detailed analyses are required to determine acceptability.

3.2.3.5.3.7 Commonality

Within Space Station - Though each module in the BB configuration will experience somewhat different thermal environments and blockage of space viewing, the degree of TCS hardware commonality between the modules should be high. However, there must be some tailoring of the body-mounted radiator location on each module to account for poor view factors to space. Since these view factors would change from IOC to growth versions, a trade must be made to determine the efficiency of radiator placement on each module. As a result, design commonality would be degraded to some degree.

Thermal insulation and coating characteristics will be similar from module to module. However, as mentioned previously, tailoring of thermal coatings, along with proper radiator placement may be required to balance the heat loads. RCS modules and antenna packages are assumed, at this preliminary stage of design, to share common thermal control elements with the primary vehicle TCS.

Commonality with platform - A free-flying platform would have a high degree of TCS commonality with the BB Space Station. Since high performance thermal coatings and fluid swivels will have been developed for the station, redesign would probably not be required for the platform. Likewise, thermal control hardware existing for the station (insulation, cold plates, heat exchangers, heat pipes, heaters, etc.) can be scaled for the appropriate thermal load.

3.2.3.5.3.8 Technology Assessment

The only technology development item peculiar to the Building Block is the need for a deployed radiator mechanism and the associated fluid swivels and

gimballing system. With the exception of fluid system features, much of this technology can be shared with the electrical power system. The on-going OAST-sponsored thermal technology program is discussed further in section 4.2.2.8.

3.2.3.6 Power Evaluation

3.2.3.6.1 Introduction

The Power System consists of three subsystems: Energy Conversion Subsystem (ECS), Energy Storage Subsystem (ESS), and Power Management and Distribution Subsystem (PMAD). For the Building Block configuration, the power system was designed to supply an average of 75 KW at IOC and 150 KW for the growth station. The system was designed with the following groundrules:

1. Ten year operational life was a design goal for the various components.
2. A modular buildup scheme was used where practical.
3. Module changeouts were permitted to achieve the 10 year operational life of the components and the extended life of the station.
4. EVA was minimized for buildup but was not prohibited.
5. A two hour period was baselined for an emergency energy storage sizing criteria. This would allow for the loss of one complete charging cycle.
6. A two axis control system was assumed to maintain the arrays perpendicular to the solar vector at all times.

3.2.3.6.2 System Overview

The power system for this configuration will consist of a deployable planar silicon solar array, regenerative fuel cell modules for energy storage, (ESS), the PMAD components, and associated thermal control elements. The solar array consists of large area silicon cells welded to a flexible kapton substrate, to form blankets. The array will be supported by an "Astromast" type structure. This system will be deployable and retractable with individual ORU's mounted on a boom and strongback structure as shown in figure 3.2.3.6.2.1. The ESS/PMAD module and thermal control radiators will also be mounted on this same structure. This is done to minimize the transfer of electricity and fluids across the moveable joints.

A breakdown of the weights is presented in table 3.2.3.6.2.1. As shown, there will be approximately 11,202 lbs. suspended on the boom at IOC and 18,168 lbs. on the boom when the growth statino is achieved. This will result in a significant portion of the total moment-of-inertia for the station being located at the arrays. Two requirements are unique to the building block configuration.

1. The ECS solar array will have to provide its own structure.
2. The ECS solar array will have to provide a method of orienting itself to the sun.

Concepts for deploying and folding the solar array structure are shown in figures 3.2.3.6.2-2 and 3.2.3.6.2-3 respectively. This concept has several features which must be mentioned. First, the array and mast can be separated from the boom and strongback. This is important to allow for growth and replacement. Second, the boom can and will be segmented to allow for packaging. Finally, the strongback can be expanded, to accommodate growth. A weight breakdown of the array and structure is shown in table 3.2.3.6.2-2.

Table 3.2.3.6.2-1. Building Block Configuration
Power System Characteristics

Solar Array (ECS)

	Weight (lbs)	Area (ft ²)
IOC	6,656	16,396
Growth	13,312	33,792

Regenerative Fuel Cell (ESS)

	Weight (lbs)
IOC	4,336
Growth	8,672

PMAD

	Weight (lbs)	Volume (ft ³)
Utility Module	1,332	13.64
Command/Control Module	646	14.08
Habitat Module	362	6.70
Logistics Module	221	3.53
Laboratory Module	372	6.56

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OF POC 3.2.3.3.2

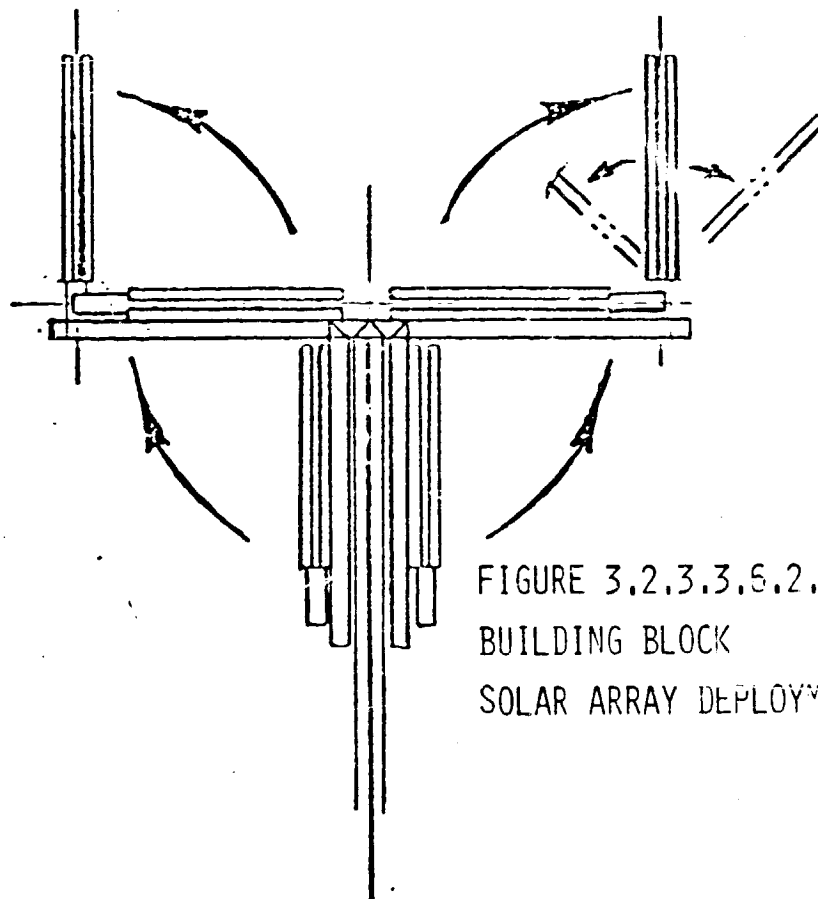
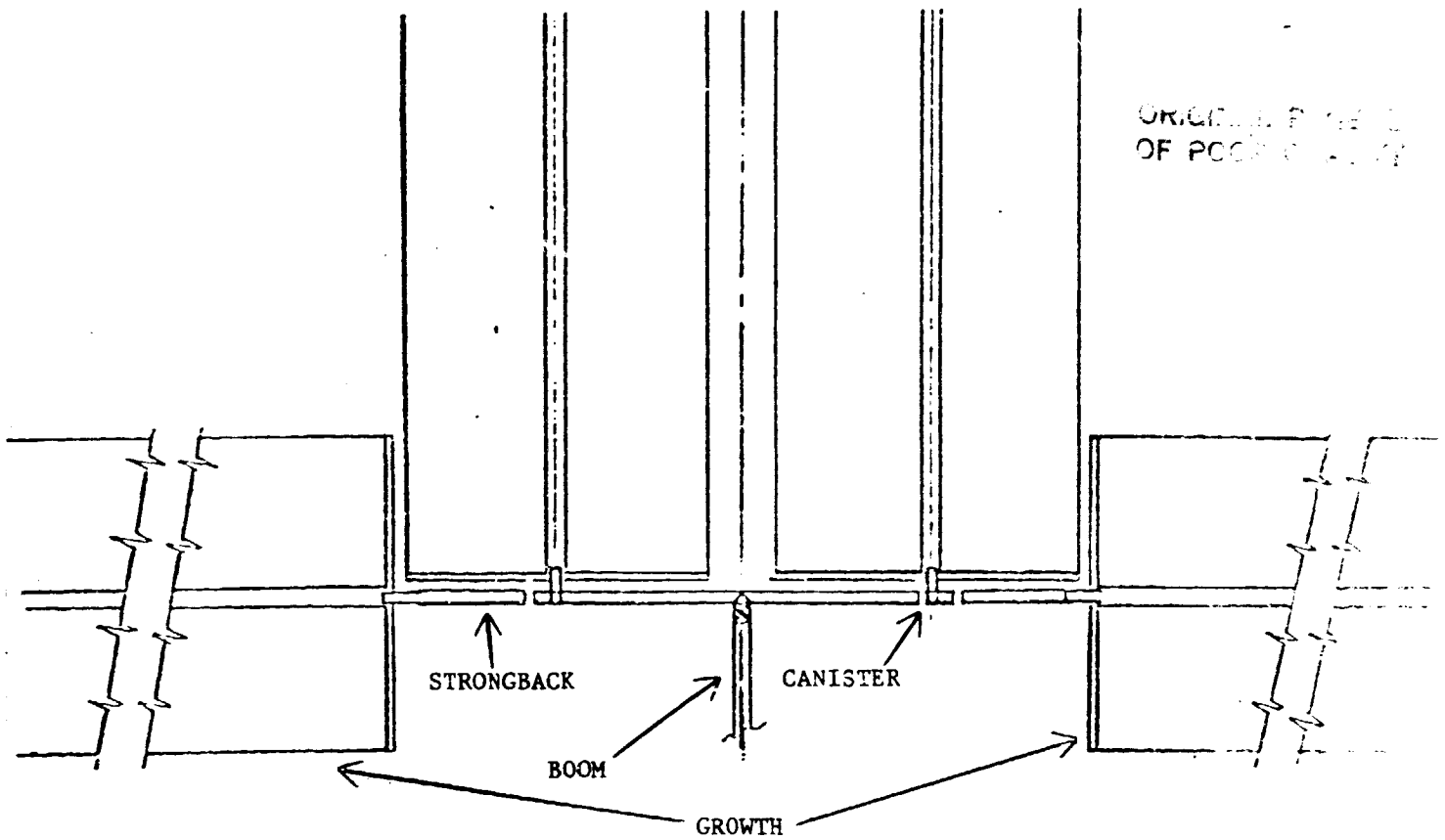


FIGURE 3.2.3.3.5.2.2
BUILDING BLOCK
SOLAR ARRAY DEPLOYMENT

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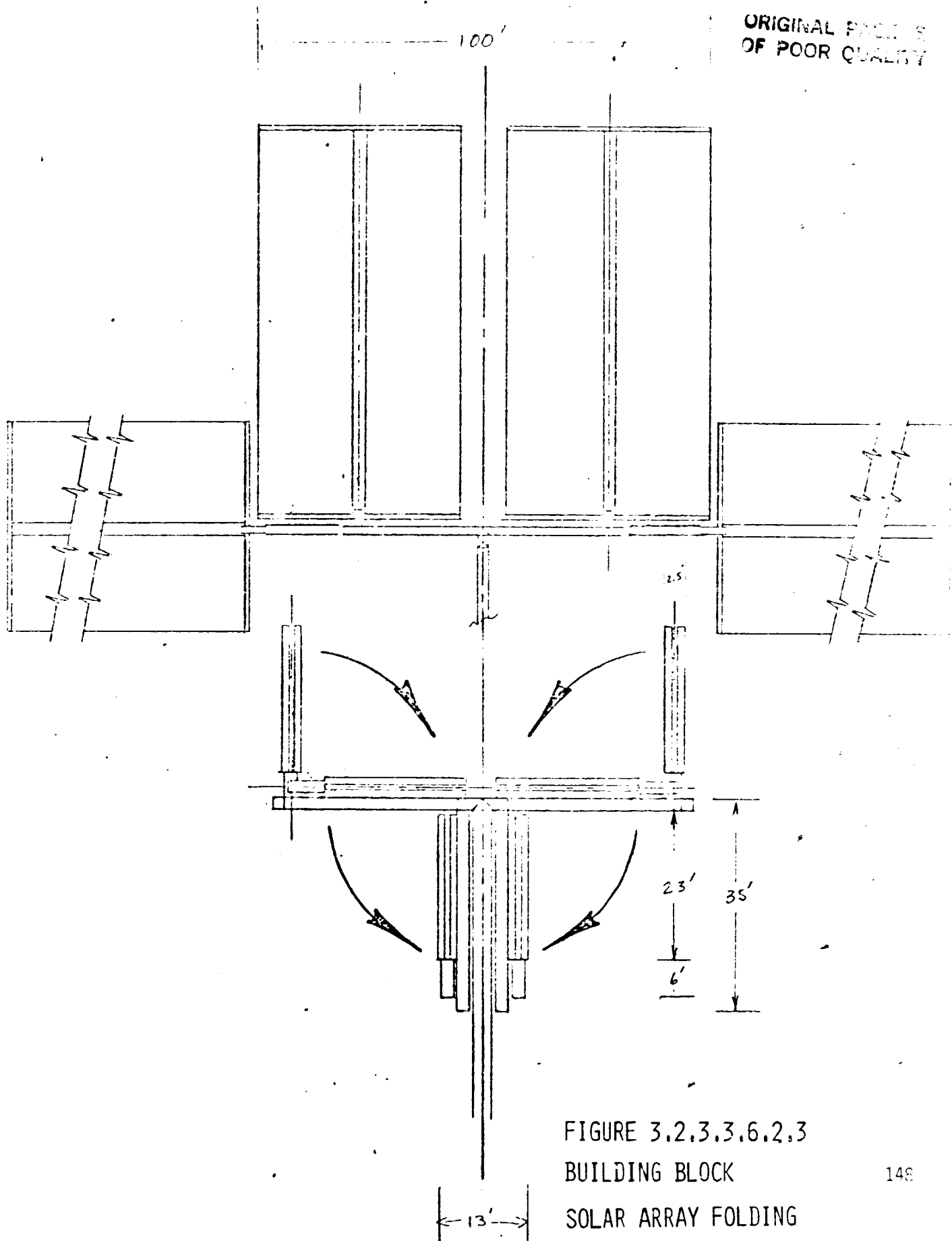


FIGURE 3.2.3.3.6.2.3

BUILDING BLOCK

SOLAR ARRAY FOLDING

TABLE 3.2.3.6.2-2

ARRAY WEIGHT SUMMARY

(FOR 37.5 KW BUS POWER/8,500 FT)
(PER RESOURCE MODULE)

BLANKET WEIGHT @ 0.27 LB/FT (INCLUDES CELLS, COVERGLASS, ETC.)	2,295 LB
ORIENTATION MECHANISM/DRIVE	25
ASTROMAST	414
TENSION/GUIDE WIRE SYSTEM	56
DEPLOYMENT MECHANISM	52
TIP FITTING	12
OUTBOARD SUPPORT BEAM	19
LOCKING LEVER	19
COVER	59
CONTAINER ASSEMBLY	108
MISC. HARDWARE	25
	<hr/>
SUBTOTAL (CANISTER & OUTBOARD)	3,084
STRONGBACK	86
MAIN BOOM (70')	158
	<hr/>
TOTAL (INCLUDING ALL STRUCTURE)	3,328 LB/RESOURCE MODULE
	<hr/>

FOR 75 KW BUS POWER, $3,328 \text{ LB} \times 2 = 6,656 \text{ LB}$

For this configuration, the ESS/PMAD module and the radiators will be located on the boom. This was done to minimize the fluid transfer problems from the ESS/PMAD module to the radiators. Also, this will provide an orientation method for the radiators, since in general they need to be perpendicular to the solar array. Since the array in this configuration is perpendicular to the solar vector at all times, it represents the minimum size.

3.2.3.6.3 Technical Evaluation

The following items should be considered for the Building Block approach:

1. Use of a two axis control system minimizes the solar array area for a given desired bus power.
2. The solar array system must provide its own structural support; significant development will be required in this area.
3. The array pointing system will require two gimbals per wing and a control system that is basically free of station interference. While this will be complex, it offers the maximum flexibility for the station, i.e., station attitude will not be significantly constrained by the array system. Some estimates show that up to 25% of the total ECS cost could be for the support/orientation elements.
4. With this configuration future developments such as GaAs concentrator arrays or solar dynamic systems could be adapted to fit the boom support system.
5. This configuration will require that electrical power be transferred across moving joints. This will dictate the use of either slip rings, roll rings, or rotary transforms and in this size range, i.e., 25 KW to 150 KW, none of these is state of the art.

6. The ESS/PMAD module is located on the boom to minimize the distance over which the array power must be transmitted and to locate it close to the thermal control radiators which eliminates the need for a flexible fluid joint.

7. The length of the boom will be dictated by a combination of shadowing and plume impingement considerations.

8. The natural frequency of the ECS will become a major design driver for the control system.

9. Initial boom design will dictate the ultimate growth capability. Growth beyond this limit will require additional supporting structure.

10. Since the entire power system is mounted externally, all hardware maintenance will require EVA's or large module changeout.

3.2.4 Operational Accommodation Evaluation

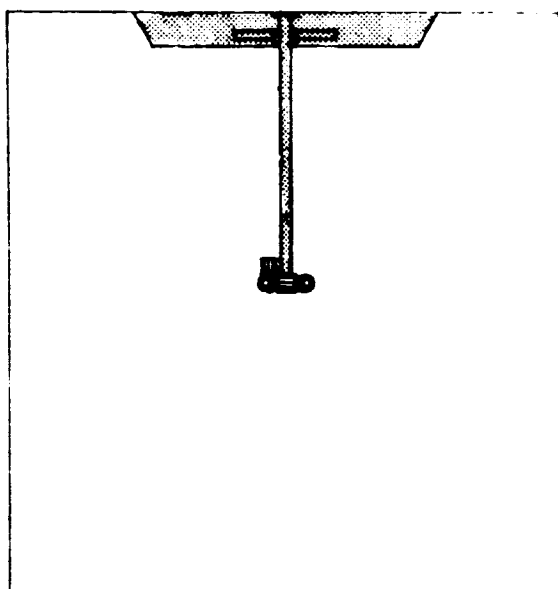
3.2.4.1 Configuration Design Considerations

3.2.4.1.1 Separation from the Space station

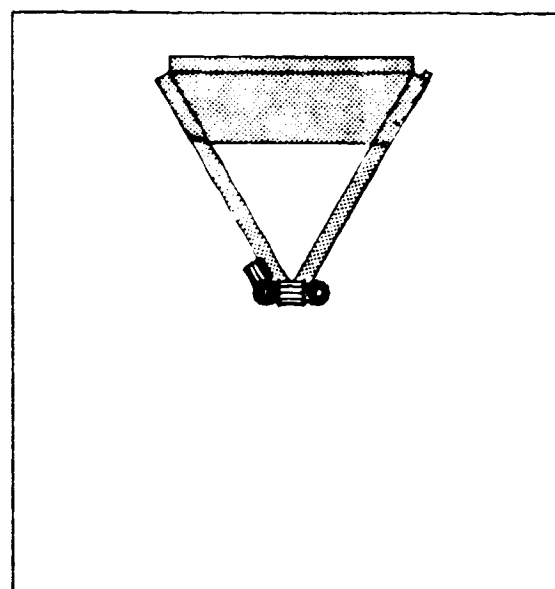
Figure 3.2.4.1-1 also illustrates the "building block" IOC. This configuration has two ports, one being located on the positive velocity vector, with the second port located in the out-of-plane (H_{bar}) direction. This implies implementation of the separation and return procedures developed for the angular momentum and velocity vectors.

As is the case with the "T" configuration, plume impingement on the solar arrays may be excessive. The initial burn separating the docked vehicle from the port is either out-of-plane or in the velocity vector direction. A radial burn follows 10 minutes later in both cases. The length of the solar arrays is approximately 117 feet extending in the out-of-plane direction. The out-of-plane sequence places the separating vehicle about 100 feet away at the initiation of the radial burn indicating a possibility for significant plume impingement on the arrays. This is clearly evident in figure 3.2.4.1-2.

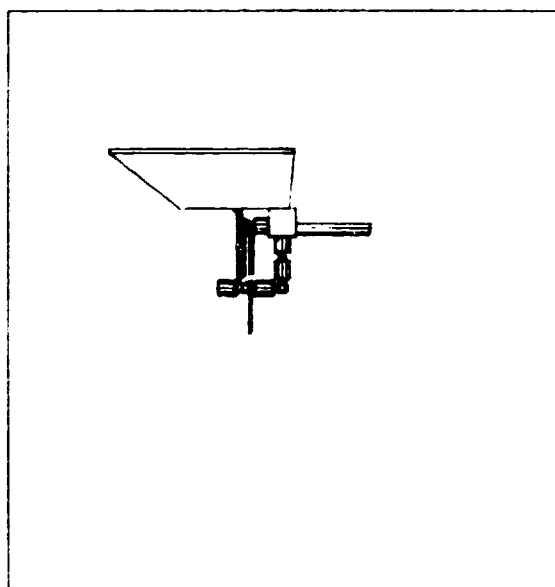
Although the figure is drawn showing the Orbiter and its VRCS jets, the situation would be similar for an OMV or OTV. The same scenario exists for a separation along the velocity vector. The boom length (about 80 feet) of the array and the "central" location of the port on the velocity vector may help to alleviate some of the impingement of the arrays. However, in either situation, the modules will be in the plume flowfield as shown in figure 3.2.4.1-3. This problem could be eliminated by waiting longer before executing the radial burn. This would place the separation vehicle further away at the time of radial burn, thereby lessening the amount of solar array area subject to impingement.



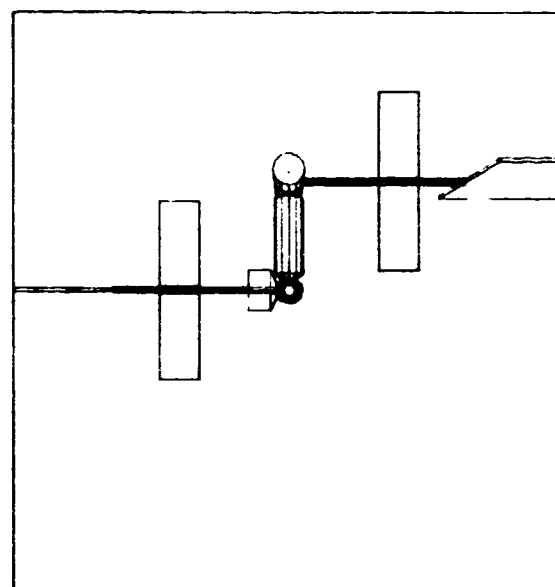
A. "T" IOC
(Velocity-vector Approach)



B. "Delta" IOC
(Inertial Approach)



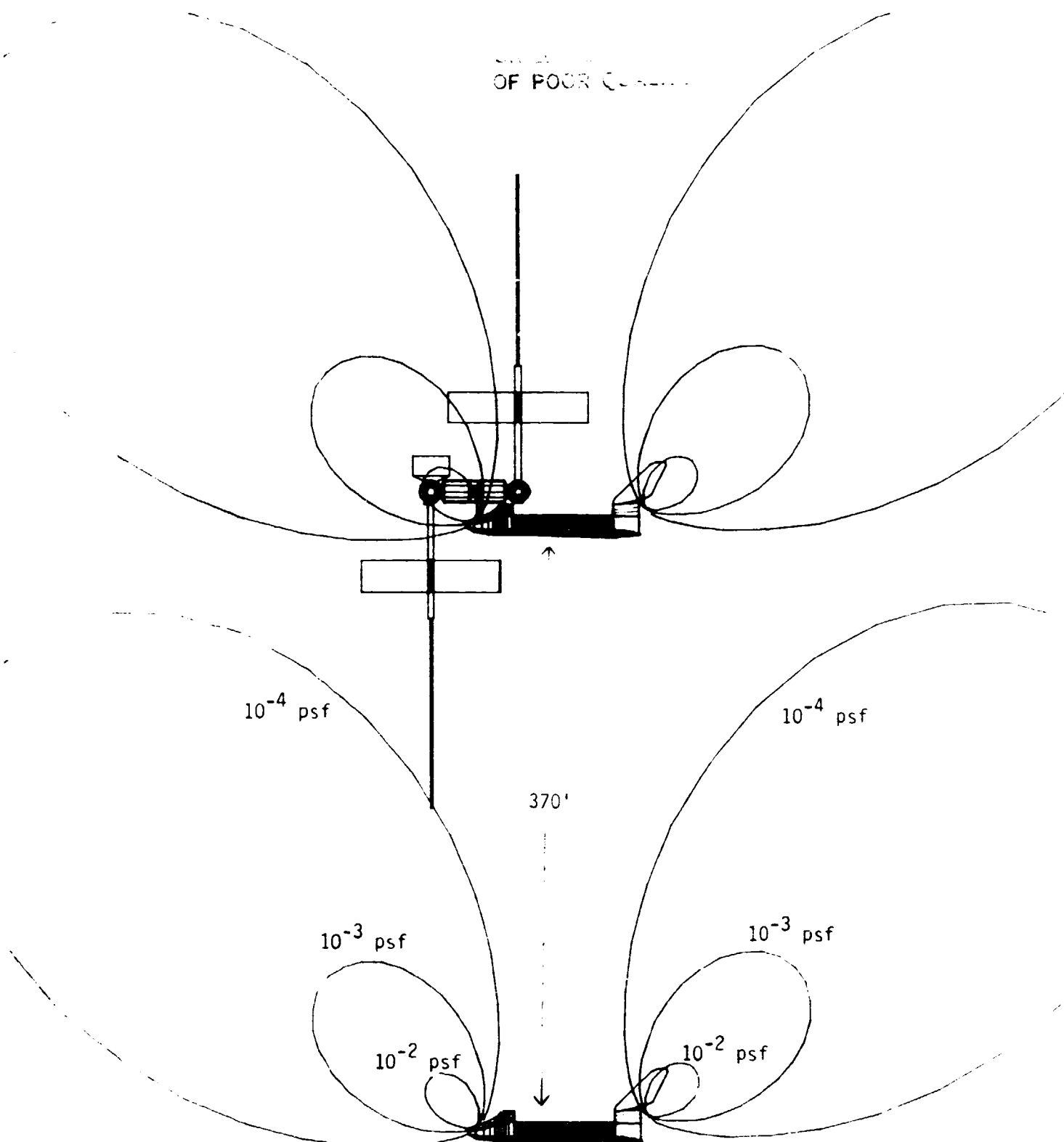
C. "Building Block" IOC
(Out-of-plane Approach)



D. "Building Block" IOC
(Velocity-vector Approach)

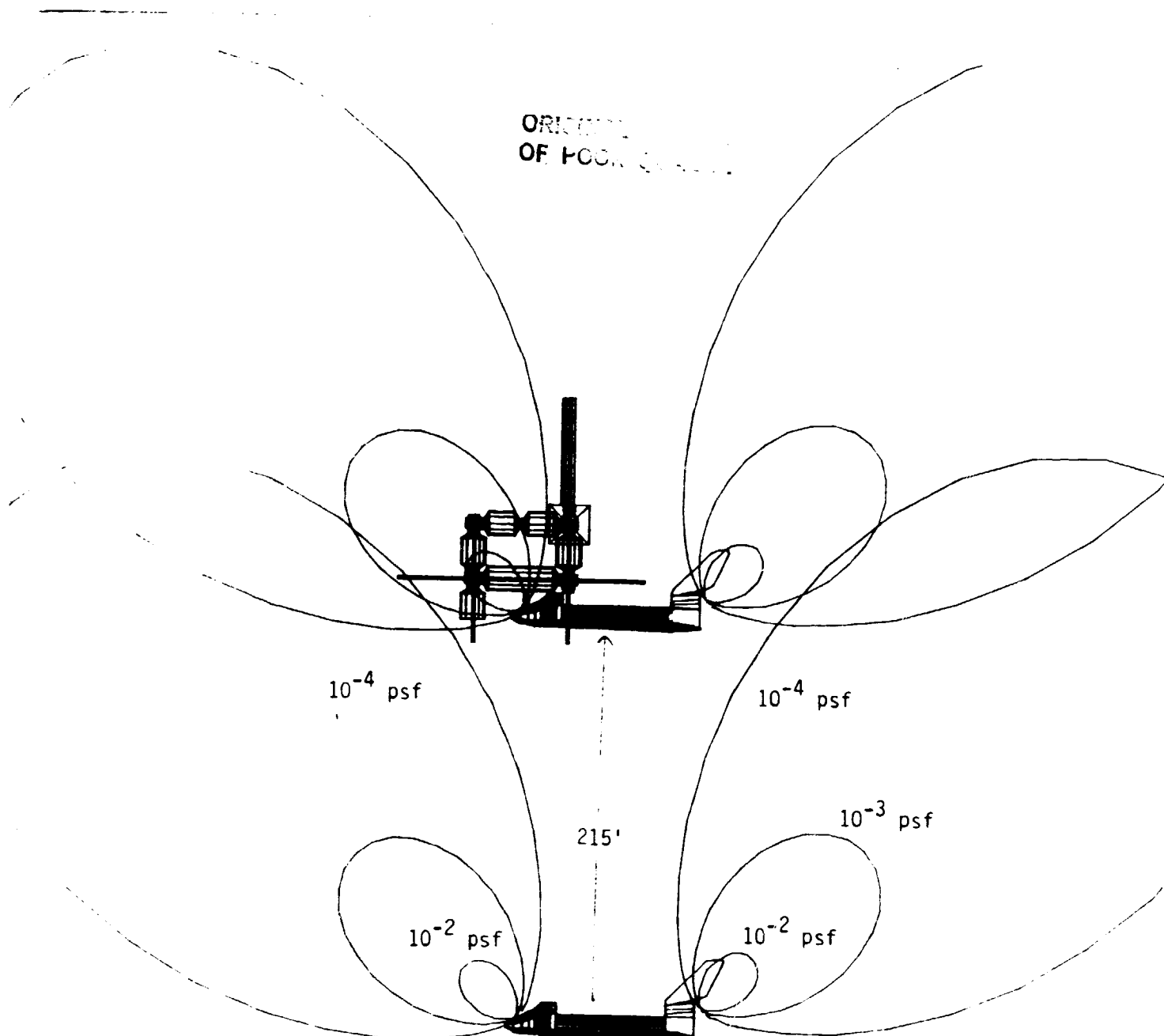
Figure 3.2.4.1-1. Orbiter Overhead Window View During Final Approach to Space Station

OF POOR CONTROL



Note: Figure assumes one nose and two tail VRCS jets added to Orbiter canted 45° from vertical.

Figure 3.2.4.1-2. VRCS Plume Dynamic Pressure Contours
(Building Block Configuration:
Out-of-Plane Separation/Approach)



Note: Figure assumes one nose and two tail VRCS jets added to Orbiter canted 45° from vertical.

Figure 3.2.4.1-3. VRCS Plume Dynamic Pressure Contours
(Building Block Configuration: Velocity
Vector Separation/Approach)

3.2.4.1.2 Return to the Space Station

The return profile necessitated by the out-of-plane docking port (on the Hbar) is somewhat undesirable. This follows directly from the comments presented in section 4.11 regarding the positive closing rate that may be present in an out-of-plane approach. The second port located on the velocity vector lends itself to the positive Vbar approach quite readily. The concerns with plume impingement are the same as those mentioned during the separation sequence and should be referred to here. With regard to the scenario of simultaneously docked Orbiters, the port locations appear to be designed such that clearance will not be a problem.

3.2.4.2 RMS Reach Capability

An integral subsystem of the Space Station will be one or more manipulators remotely operated and used to perform a variety of operations. Some of the more critical requirements of a station manipulator will be station assembly, module removal, OMV/OTV berthing in the hangar area, deployment of the OMV/OTV from the hangar area, as an aid to OMV, OTV and satellite servicing, and possibly as an aid to Orbiter/station berthing. The analysis conducted in support of this document emphasized the use of the current Shuttle RMS to the maximum extent possible for assembly of the Building Block concept. A "special" station manipulator was considered only for those operations which exceeded the reach capability of the Shuttle RMS.

The RMS/station manipulator analysis was performed using the RMS Desk Top Planing Simulation (RPS) developed for RMS mission planning activities and used to define RMS payload handling capabilities and procedures for STS missions. The program was updated and modified to include the Building Block configuration as well as a generalized manipulator in the sense that the length of the manipulator booms can be varied to accommodate larger reach envelopes than the current RMS. The number of active joints can be reduced and the booms shortened so that a Handling and Position Aid (HPA) type of mechanism can also be accurately simulated.

The manipulator analysis included herein, is based on a kinematic model of the RMS in that no rigid or flexible body dynamics are included. This limitation, however, does not invalidate the feasibility of using the RMS for station assembly since all modules handled are within the weight and inertia limits verified for standard RMS operations. The study results are based on the current RMS control algorithms and software and verify the reach capability as well as the maneuver path for both the RMS and the station manipulator. The simulation also checks for singularities and joint reach limits. In summary, all maneuvers studied for the Building Block configuration assembly sequence should be valid with the exception of possible crew visibility constraints. RMS operator eye-point and CCTV views can also be generated using the RPS simulation, and these results will be reported in future documentation. In performing the kinematic analysis to assess the RMS capability to remove station modules from the Orbiter payload bay and assemble the station, the following assumptions were used.

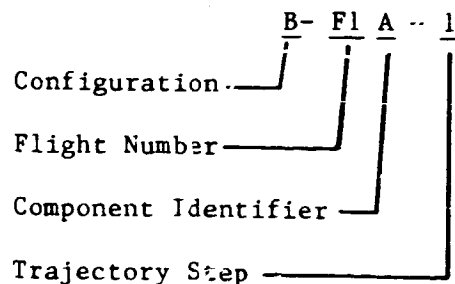
1. Port and starboard RMS's are available
2. Once the C/C module and an interface module are mated, all remaining construction using the Orbiter RMS's will be accomplished with the Orbiter

firmly docked to the Space Station.

3. Grapple fixture location and orientation are identical on all modules of the same type.

4. Payload bay locations consider only RMS reach capability and not Orbiter c.g. restrictions.

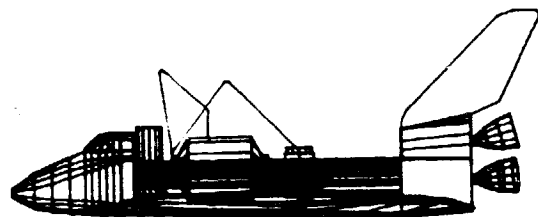
Figures 3.2.4.2-1 through 3.2.4.2-7 illustrate an assembly sequence for the IOC version of the Building Block configuration. Each figure represents a "snapshot" of the entire maneuver that was performed on the RPS simulation to verify the RMS reach capability, that the entire maneuver path was free of RMS singularities, and that reach limits were not encountered. Each figure label reads as follows:



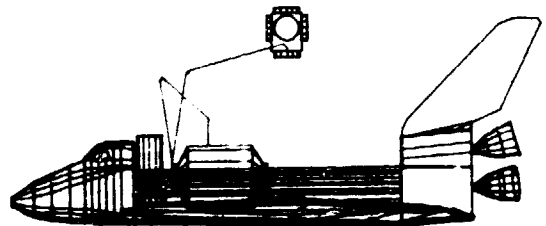
The component identifier appears only in labels where more than one component to be assembled is manifested in the cargo bay for that flight. The trajectory step refers to the sequenced "snapshots" of the RMS configurations during a specific maneuver.

Flight one carries to orbit the first C/C module and the first Interface Module (IM) with a solar array. The assembly sequence shown in figure 3.2.4.2-1 uses a port and starboard RMS to deploy and mate these two modules. The combination is then docked to the Orbiter and the solar array deployed. Figure 3.2.4.2-2 shows the Flight 2 assembly sequence once the Orbiter is docked to the IM. The port RMS can adequately maneuver the habitability module from the Orbiter bay to its docked position on the IM as shown in the

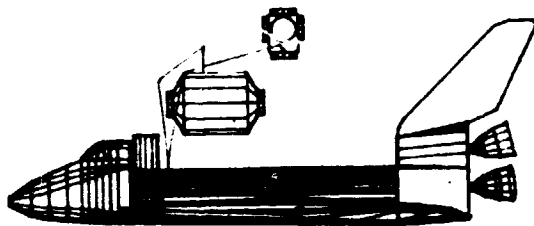
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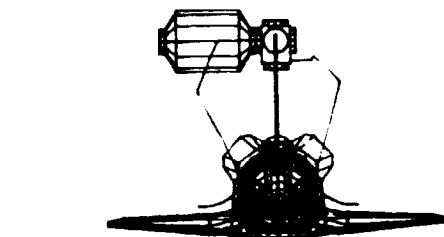
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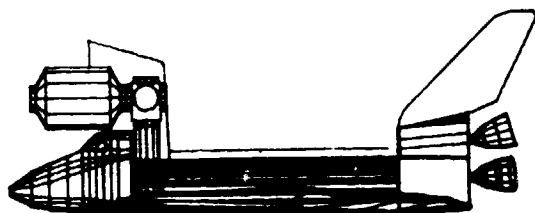
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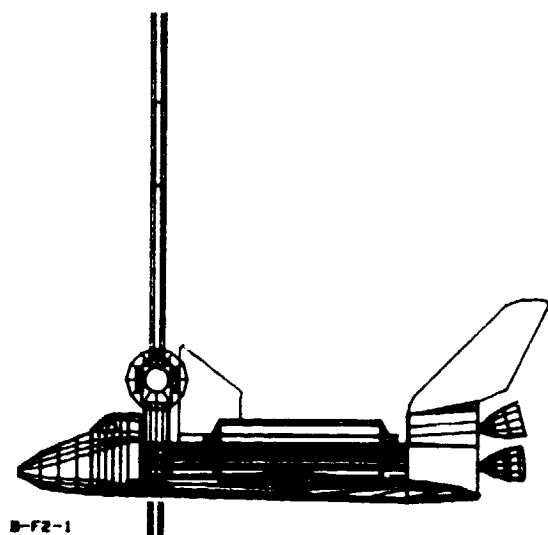


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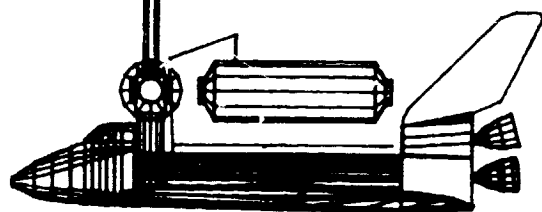


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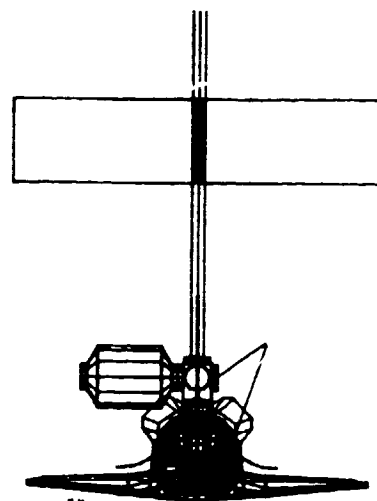
Figure 3.2.4.2-1. Building Block Assembly - C/C
module and interface module



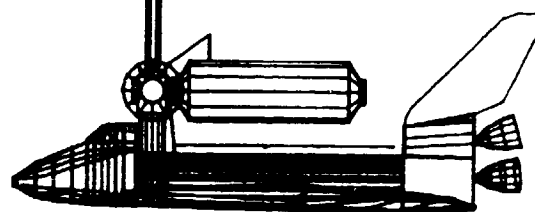
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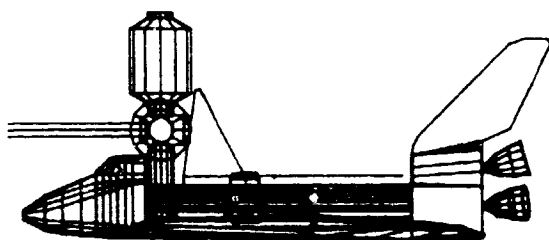


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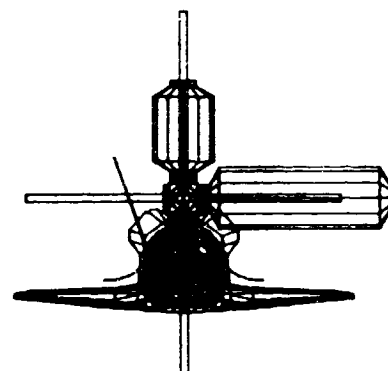
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Figure 3.2.4.2-2. Building block assembly - Habitat Module

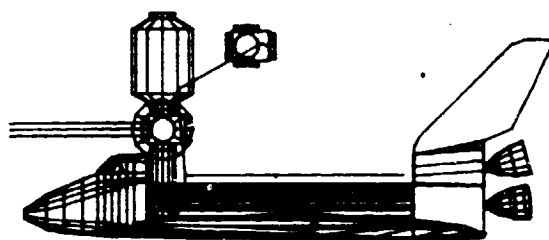
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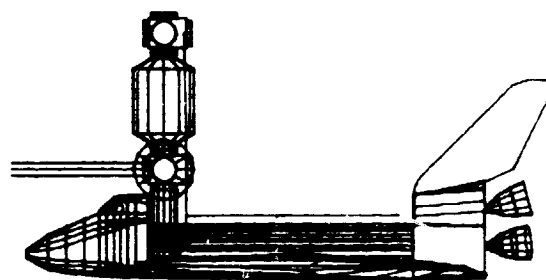
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Figure 3.2.4.2-3. Building Block Assembly - Interface Module and Station Manipulator

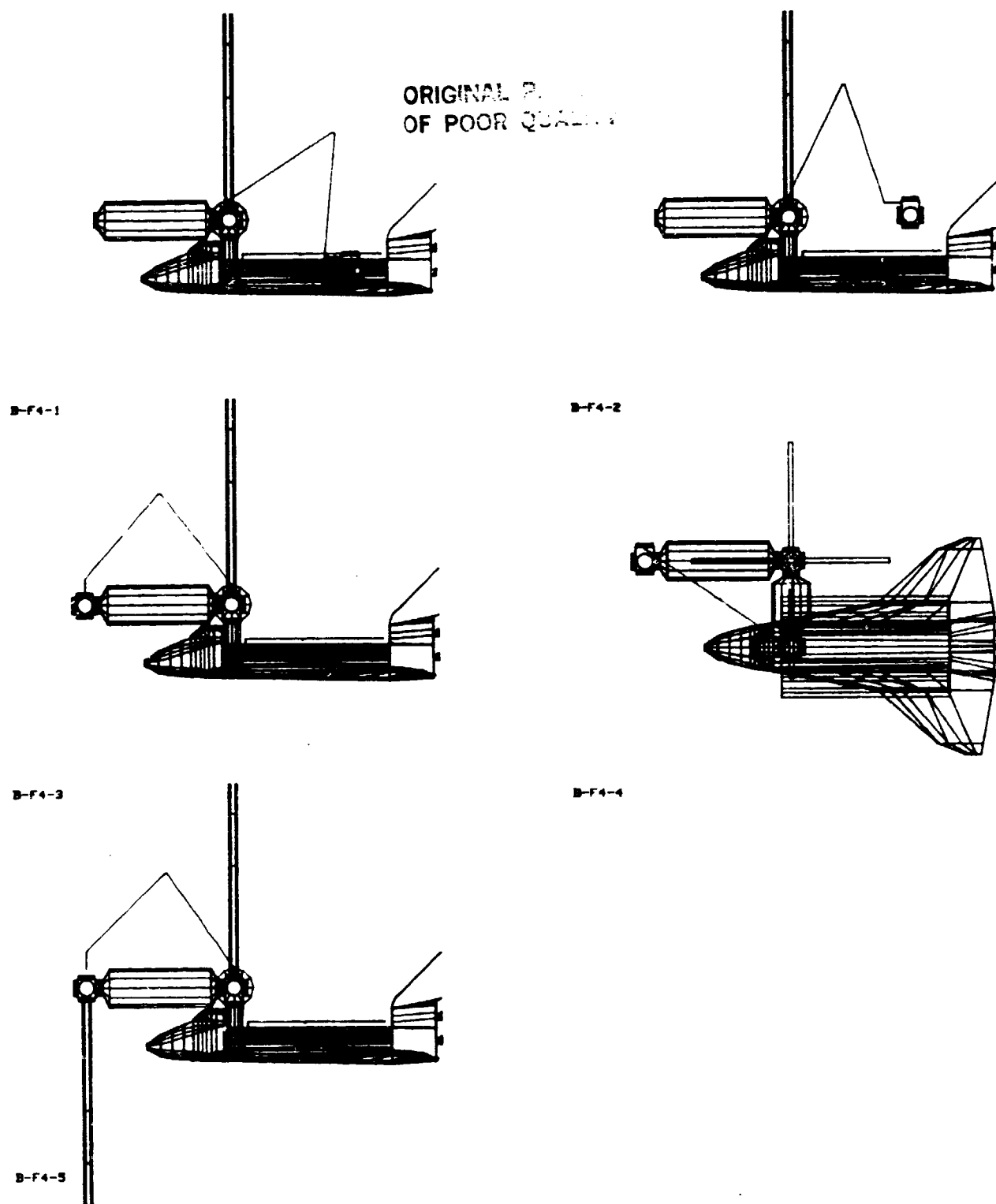


Figure 3.2.4.2-4. Building Block Assembly - Interface
Module/Solar Array

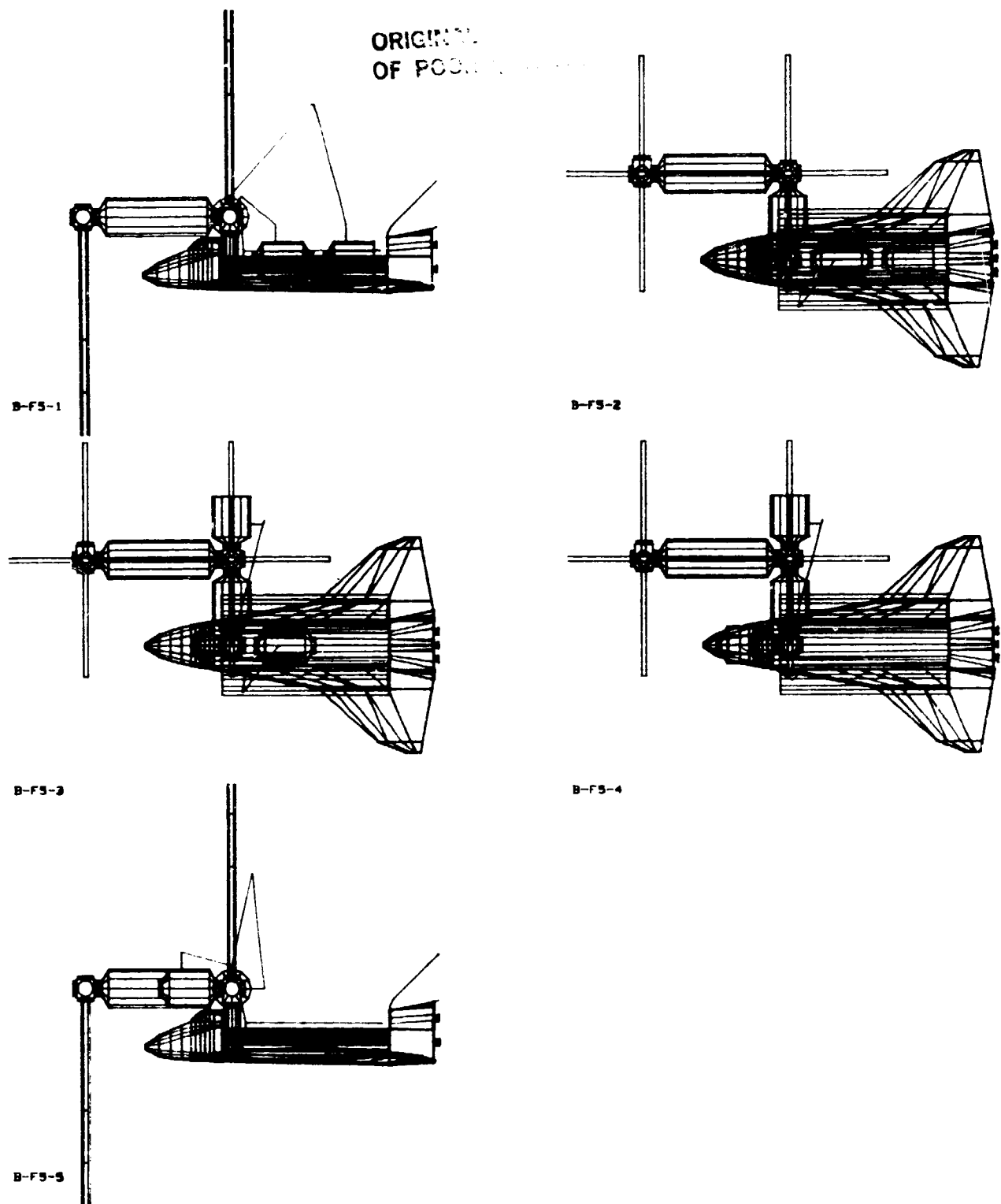


Figure 3.2.4.2-5. Building Block Assembly - Lab
Module and Logistics Module

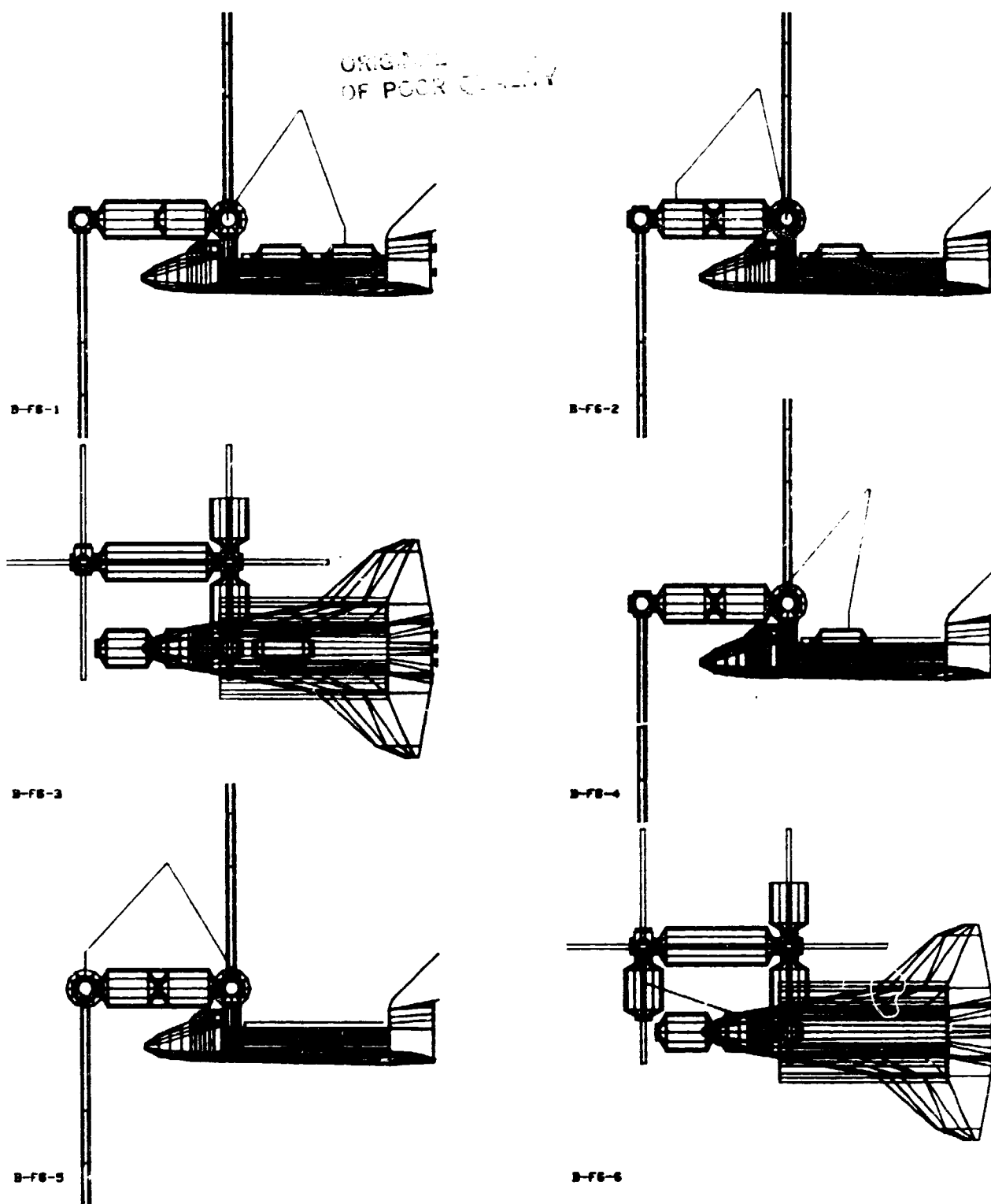


Figure 3.2.4.2-6. Building Block Assembly - Second Lab Module and Second C/C Module

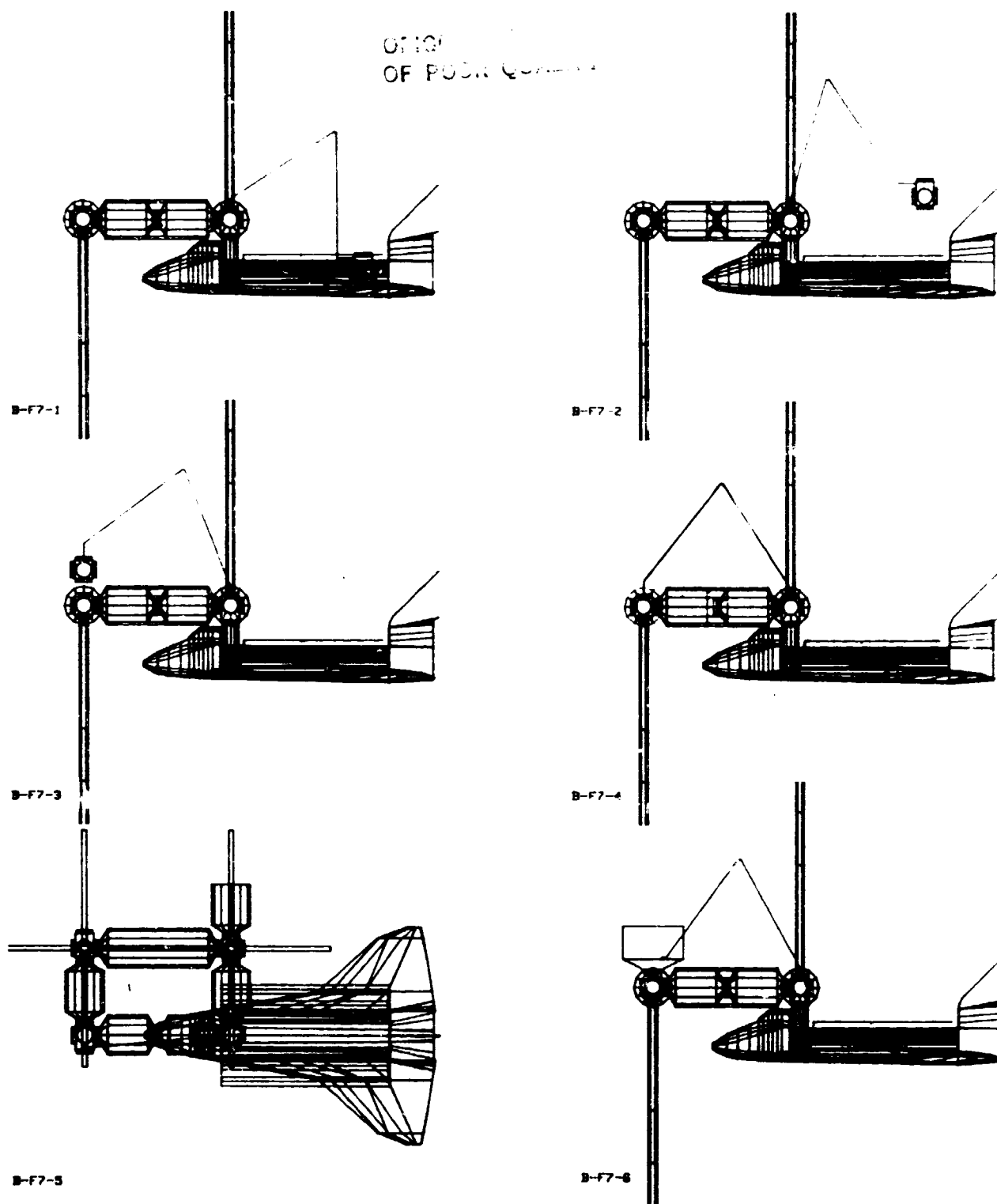


Figure 3.2.4.2-7. Building Block Assembly - Interface Module and OMV Hunger

steps of the figure.

Figure 3.2.4.2-3 represents Flight 3 in which an interface module and the Station Manipulator (SM) are brought up. The interface module is placed on the open end of the C/C module and the station manipulator is placed on an out-of-plane port of this interface module. With upper and lower arm boom lengths of 45 feet each, the station manipulator has adequate reach capability to assist in the completion of the station assembly.

Flight 4 docks the interface module containing the second solar array to the habitability module as shown in figure 3.2.4.2-4 using the station manipulator.

Flight 5 which is illustrated in figure 3.2.4.2-5 utilizes the station manipulator and the port RMS for this assembly sequence. The first lab module is docked using the port RMS. The station manipulator maneuvers the logistics module to the interface module located between the C/C and habitability modules as shown in the figure.

The second lab module and second C/C module are brought up on flight 6 and docked to the station using the station manipulator and illustrated in figure 3.2.4.2-6. The remaining IM and OMV hangar carried on flight 7 can be maneuvered into their proper location using the station manipulator. This final assembly sequence completes the "race track" and is shown in figure 3.2.4.2-7.

3.2.5 Safety Accommodations

The safety accommodations provided for the IOC (Initial Operational Configuration) Phase (Phase I) were used for the basic concept evaluation since this was considered the most critical with respect to crew safety. The additional volume available during Phase IV increases the time of reaction

to a leak to approximately 85 minutes (see section 3.2.5.5). Otherwise, the comments are applicable to both Phase I and Phase IV.

3.2.5.1 General

The Building Block Configuration appears to satisfy the broad crew safety requirements. This assumes that the design and operational constraints specified in Space Station Configuration Books 3 and 6 are implemented during continued station development and operation.

3.2.5.2 All Habitable Modules (Habitat, Laboratories, Interface and C/C) Egress Capability

Dual egress paths from each module are incorporated.

3.2.5.2.1 Logistics Module

Book 3 Systems Requirements and Characteristics specifically exempts the logistics module from the "two or more entry/egress paths." The logistics module has only one egress path, the risk to a crewmember occupying this volume during the occurrence of an accident forcing evacuation of the volume could probably be reduced to an acceptable level by proper location of equipment, adequate materials control, elimination of potential ignition sources, and maintenance of adequate traverse clearance during operations in the module.

3.2.5.3 Enclosure of High-Pressure or Hazardous Fluid Tanks

The logistics module will be divided into a pressurized section and an unpressurized section. High pressure and hazardous fluids will be transported in the unpressurized section to avoid the possibility of fluids propagating into other modules or cause overpressurization of one or more modules. The separation distance of various tanks has not been defined.

3.2.5.4 Isolation of Modules after Accident Occurrence

One problem that arises from the provision of dual egress routes from a habitable module is the complexity of the process of sealing off that module after such things as a spill of a toxic fluid. This suggests the desirability of a self-contained environmental control circulation system for modules such as the laboratories to minimize the potential for cross-contamination of modules while the hatches at each end of the contaminated module are being closed.

3.2.5.5 Reaction Time after Occurrence of a Leak

The Safety Division position, with respect to hatch management, is that all hatches should be normally open to create ease of transit from module to module, reduce the wear on hatch mechanisms, prevent hatch opening difficulties because of small pressure differentials, and maintain the maximum volume for bleed down in case of a leak. Of these reasons, the last is probably most significant, considering the large number of sealing surfaces and the increased potential for a leak. In the IOC configuration of the Building Block, a rough calculation of the time to react to the occurrence of a leak equivalent to a one-inch diameter hole would be 60 plus minutes, assuming a 95 percent efficient orifice, an occupancy of 25% solids in the station, and a reduction of pressure from 14 to 9.1 psia. If a leak detector sufficiently accurate to determine the module containing the leak is available, this should allow adequate time to react to the occurrence by evacuating and sealing off the affected module.

3.2.5.6 EVA Operations

The antenna locations are apparently such that radiation hazards to EVA crewmembers are minimal, but some Reaction Control System (RCS) package locations may require thruster deactivation during EVA. The system geometry

should allow ready design and implementation of adequate EVA traverse and work station retention mechanisms.

3.2.5.7 Repair and Reactivation of Modules after an Accident

Adequate airlock provisions are provided to allow Intervehicular Activity (IVA) suited reentry into a module that has been isolated because of an accident to perform necessary repair or reconfiguration to permit continued use of the module.

3.2.5.8 Multiple Orbiter Docking Ports

The ability to dock with and access the Orbiter from various volumes of the Space Station is acceptable.

3.2.6 Costs

3.2.6.1 Groundrules and Assumptions

The following groundrules and assumptions were used in the cost analysis for the Building Block configuration:

- o The Space Station Cost Model (SSCM) developed by Planning Research Corporation (PRC) was used to develop hardware and system level costs.
- o The concept was treated as one work package.
- o The IOC configuration only was costed.
- o No learning was assumed.
- o No explicit reserve was included.
- o No STS flight costs were included
- o Subsystem costs were allocated to the modules on the basis of weight.
- o Costs are expressed in millions of 1984 constant year dollars. Since SSCM outputs costs in 1982\$, the inflation adjustment was made using the NASA

R&D inflation index (1.175 for 1982 to 1984 dollars).

- o Program level costs (including fee) were included using the Code B factors.
- o Complexity factors considered to be 1.0 except the following:
 - o Closed loop ECLS was costed using the open loop ECLS CER with 1.6 complexity factor. Factor based on CDG trade study.
 - o Berthing and docking adapter used a 0.8 complexity factor and used the ASTP adapter as an analogy.
 - o Complexity factor of 0.6 used for fuel cell based on JSC analysis.
 - o GSE complexity factor of 0.8 was used, based on CDG cost estimate.

3.2.6.2 Presentation of Results

Figure 3.2.6-1 presents the results of the SSCM for the Building Block approach. The model computes the DDT&E and the first unit costs. The costs shown are for one of each Space Station module or element (i.e., hab module, boom array, etc.) Therefore, figure 3.2.6-1 does not show the total cost of the station.

Figure 3.2.6-2 presents the DDT&E and First Unit Costs after being spread to the different modules. The three parts to this figure present cost spreads by module for DDT&E, Production, and total costs. As with the previous figure, the costs shown for the production phase are for the first unit of each of the modules.

Figure 3.2.6-3 presents the summary of the costs by quantities and types of modules that comprise the IOC configuration. The first two cost columns recap the totals found in figure 3.2.6-2 for DDT&E and Production (First Unit). The third cost column is the total production costs taking into account the quantities of each module or element. The final column is the total of the DDT&E and Production costs and is therefore, the total of the Space Station at IOC.

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FIGURE 3.2.6-1

SPACE STATION COST MODEL

BLDG BLOCK CONCEPT

INFL FACTOR: 1.175 FY84 \$\$ (IN MILLIONS)

SUBSYSTEM	WEIGHT	D&D CMPLX	D&D COST	TOTAL UNITS	PROD COST	TOTAL COST
STRUCTURE			561.9		620.1	1182.0
..CUBE	1896	1.00	60.7	4.00	52.1	112.8
..CYLINDER	2641	1.00	73.2	15.00	237.7	310.8
..ENDCAP	931	1.00	40.6	12.00	102.5	143.1
..SECOND'Y	23001	1.00	277.4	1.45	71.6	349.0
..DOCK ADAPT	600	0.80	10.3	12.00	15.8	26.1
..BERTH ADAPT	600	0.80	10.3	28.00	36.8	47.1
..CMPLX MECH	1812	1.00	68.0	3.65	91.2	159.2
..MECH'ISMS	905	1.00	21.5	3.26	12.6	34.0
THERMAL	5701	1.00	105.2	3.69	132.2	237.4
G N & C			159.0		147.4	306.4
..ELECTRONICS	78	1.00	116.8	6.92	90.4	207.2
..CMG	650	1.00	40.3	6.00	45.0	85.2
..MAG TORQ	120	1.00	2.0	6.00	12.0	14.0
RES	1223	1.00	8.2	2.22	4.7	12.9
POWER			98.8		185.9	284.7
..SOLAR (KW)	89.3	1.00	26.3	2.00	107.8	134.1
..BATT	0	1.00	0.0	1.00	0.0	0.0
..DIST,REG	258	1.00	15.3	12.93	18.1	33.5
..FUEL CELL	1680	0.60	57.1	4.00	60.0	117.1
COMM & DATA	3212	1.00	197.2	4.64	171.5	368.7
ECLSS	5335	1.60	249.5	3.80	222.7	472.2
CREW PROV	1808	1.00	39.2	3.86	30.0	69.2
THRUPUT	0	0.00	0.0	0.00	0.0	0.0
HDM SUBTOTAL			1419.1		1514.5	2933.6
SYS TEST HDM		1.00	1215.0		0.0	1215.0
INST, ASSY, & C/O		1.00	165.6	1.64	167.2	332.8
SYS TEST OPNS		1.00	603.0		0.0	603.0
GR SPT EQMT		0.80	471.8		0.0	471.8
SYS ENGR & INT		1.00	328.2	1.64	112.0	440.2
PROG MGMT		1.00	242.6	1.64	139.9	382.5
SYS TOTAL			4445.3		1933.5	6378.8
PROG SPT (14%)			622.3		270.7	893.0
MGT & INT (5%)			253.4		110.2	363.6
FEE (8%)			425.7		185.2	610.8
PROG TOTAL			5746.7		2499.6	8246.3

FIG. 3.2.6-2A

COST SUMMARY- BLDG BLOCK

DDTE PHASE

OBSERVED COSTS
OF POOR QUALITY

SUBSYSTEM	SUBSYS TOTALS	COST (MILLIONS OF 84 \$\$)								
		C/C	HAB	LAB	IM1	A/L	BA1	OMV	SSS	LOG
STRUCTURE	561	65	104	60	76	55	48	37	75	41
..PRESSURIZED	175	24	43	24	30	30	0	0	0	24
..SECONDARY	277	39	59	31	16	16	24	19	60	16
..DOCK & BERTH	21	1	1	5	6	6	0	0	0	1
..MECH'ISMS	89	1	1	1	24	3	24	18	16	1
THERMAL	105	24	13	57	0	0	11	0	0	0
G N & C	159	11	2	2	68	77	0	0	0	0
..ELECTRONICS	117	9	2	2	55	50	0	0	0	0
..CMG	40	0	0	0	13	27	0	0	0	0
..MAG TORQUERS	2	2	0	0	0	0	0	0	0	0
RCS	8	0	0	0	0	8	0	0	0	0
POWER	99	5	3	4	0	0	85	0	0	2
..SOLAR ARRAY	26	0	0	0	0	0	26	0	0	0
..BATTERIES	0	0	0	0	0	0	0	0	0	0
..COND & REG	15	5	3	4	0	0	2	0	0	2
..FUEL CELL	57	0	0	0	0	0	57	0	0	0
COMM & DATA	197	85	23	16	3	3	62	4	1	1
ECLSS	250	92	77	29	0	0	0	0	0	52
CREW PROV	39	3	35	1	0	0	0	0	0	0
THROUGHPUT	0	0	0	0	0	0	0	0	0	0
SUBTOTAL	1418	284	257	169	147	142	206	41	77	96
SYS TEST HDWE	1215	243	220	144	126	122	176	35	66	82
INT, ASSY, & C/O	166	33	30	20	17	17	24	5	9	11
SYS TEST OPN	603	121	109	72	62	60	87	18	33	41
GR SPT EQMT	472	95	85	56	49	47	68	14	25	32
SYS EMGR & INT	328	66	59	39	34	33	48	10	18	22
PROG MGMT	243	49	44	29	25	24	35	7	13	16
TOTAL	4444	891	804	528	460	445	645	129	240	302
PROG SPT (14%)	622	125	113	74	64	62	90	18	34	42
MGT & INT (5%)	253	51	46	30	26	25	37	7	14	17
FEE (8%)	426	85	77	51	44	43	62	12	23	29
TOTAL	5745	1151	1039	683	595	576	834	167	310	390

FIG. 3.2.6-2B

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COST SUMMARY- BLDG BLOCK

FIRST UNIT - PROD PHASE

SUBSYSTEM	SUBSYS		COST (MILLIONS OF 84 \$\$)							
	TOTALS	C/C	HAB	LAB	IM1	A/L	BA1	DMV	SSS	LOG
STRUCTURE	412	63	114	64	38	34	9	12	21	57
..PRESSURIZED	269	49	96	49	13	13	0	0	0	49
..SECONDARY	50	7	10	6	3	3	4	3	11	3
..DOCK & BERTH	29	3	3	5	8	8	0	0	0	3
..MECH'ISMS	65	4	4	4	15	11	5	9	10	3
THERMAL	75	18	16	31	1	0	8	0	0	1
6 N & C	74	8	1	1	33	32	0	0	0	0
..ELECTRONICS	46	2	1	1	25	17	0	0	0	0
..CMG	23	0	0	0	8	15	0	0	0	0
..MAG TORQUERS	6	6	0	0	0	0	0	0	0	0
RCS	2	0	0	0	0	2	0	0	0	0
POWER	95	3	3	3	0	0	84	0	0	2
..SOLAR ARRAY	54	0	0	0	0	0	54	0	0	0
..BATTERIES	0	0	0	0	0	0	0	0	0	0
..COND & REG	12	3	3	3	0	0	0	0	0	2
..FUEL CELL	30	0	0	0	0	0	30	0	0	0
COMM & DATA	96	40	14	12	1	2	21	4	1	1
ECLSS	147	52	48	24	0	0	0	0	0	23
CREW PROV	24	3	19	2	0	0	0	0	0	0
THROUGHPUT	0	0	0	0	0	0	0	0	0	0
SUBTOTAL	926	186	214	137	74	70	122	16	22	85
SYS TEST HDWE	0	0	0	0	0	0	0	0	0	0
INT, ASSY, & C/O	102	21	24	15	8	8	13	2	2	9
SYS TEST OPN	0	0	0	0	0	0	0	0	0	0
GR SPT EQMT	0	0	0	0	0	0	0	0	0	0
SYS ENGR & INT	68	14	16	10	5	5	9	1	2	6
PROG MGMT	36	17	20	13	7	6	11	1	2	8
TOTAL	1182	237	274	175	94	89	156	20	28	108
PROG SPT (14%)	165	33	38	24	13	13	22	3	4	15
MGT & INT (5%)	67	14	16	10	5	5	9	1	2	6
FEE (8%)	113	23	26	17	9	9	15	2	3	10
TOTAL UNIT	1528	307	354	226	121	116	202	26	36	140

FIG. 3.2.6-2C

OF 2

COST SUMMARY- BLDG BLOCK

DDTE + FIRST UNIT

SUBSYSTEM	SUBSYS TOTALS	COST (MILLIONS OF 84 \$)								
		C/C	HAB	LAB	IMI	A/L	BA1	OMV	SSS	LOG
STRUCTURE	973	127	218	124	114	89	57	49	96	99
..PRESSURIZED	443	72	140	72	43	43	0	0	0	72
..SECONDARY	327	46	69	36	18	18	28	22	70	19
..DOCK & BERTH	50	4	4	10	14	14	0	0	0	4
..MECH'ISMS	154	5	5	5	39	13	29	27	26	4
THERMAL	180	42	29	88	1	0	19	0	0	1
6 W & C	233	19	3	3	101	108	0	0	0	0
..ELECTRONICS	162	11	3	3	80	67	0	0	0	0
..CMG	63	0	0	0	21	42	0	0	0	0
..MAG TORQUERS	8	8	0	0	0	0	0	0	0	0
RCS	10	0	0	0	0	10	0	0	0	0
POWER	194	8	5	7	1	1	169	0	0	4
..SOLAR ARRAY	80	0	0	0	0	0	80	0	0	0
..BATTERIES	0	0	0	0	0	0	0	0	0	0
..COND & REG	27	8	5	7	1	1	2	0	0	4
..FUEL CELL	87	0	0	0	0	0	87	0	0	0
COMM & DATA	293	125	37	28	4	4	82	8	2	3
ECLSS	397	143	125	53	0	0	0	0	0	75
CREW PROV	63	6	54	3	0	0	0	0	0	0
THROUGHPUT	0	0	0	0	0	0	0	0	0	0
SUBTOTAL	2343	470	471	306	220	212	328	57	99	181
SYS TEST HDWE	1215	243	220	144	126	122	176	35	66	82
INT, ASSY, & C/O	268	54	54	35	25	24	38	7	11	21
SYS TEST OPN	603	121	109	72	62	60	87	18	33	41
GR SPT EQMT	472	95	85	56	49	47	68	14	25	32
SYS ENGR & INT	397	80	75	49	39	38	57	11	19	29
PROG MGMT	328	66	64	41	32	31	46	9	15	24
TOTAL	5626	1128	1078	703	554	535	801	150	268	410
PROG FEE (14%)	788	158	151	98	78	75	112	21	38	57.34
MGT & INT (5%)	321	64	61	40	32	30	46	9	15	23.34
FEE (8%)	539	108	103	67	53	51	77	14	26	39.22
TOTAL	7273	1458	1393	909	716	691	1035	193	347	529

FIG. 3.2.6-3

BLDG BLOCK CONFIGURATION

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OF FOUR QUALITY

COST SUMMARY BY MODULE

QTY	MODULE	DDTE	FY84\$\$ (IN MILLIONS)		TOTAL
			UNIT	PROD	
2	CMD & CNTRL	284	186	372	656
1	HAB MOD	257	214	214	471
2	LAB MOD	169	137	274	443
2	I/F MOD	147	74	147	294
2	A/L MOD	142	70	140	282
2	SOLAR BOOM	206	122	244	450
1	HANGAR	41	16	16	57
1	SAT SPT SYS	77	22	22	99
1	LOG MOD	96	85	85	181
<hr/>					
	HQW SUBTOTAL	1418	926	1514	2343
	SYS TEST HQW	1215	0	0	1215
	INT, ASSY, C/O	136	102	167	333
	SYS TEST OPN	603	0	0	603
	GR SPT EQMT	472	0	0	472
	SYS ENG & INT	328	68	112	440
	PROG MGMT	243	85	140	382
	SYS TOTAL	4444	1182	1933	6377
	PROG SPT	622	165	271	893
	MGT & INT	253	67	110	363
	FEE	426	113	195	611
	PROG TOTAL	5745	1528	2499	8244

3.3 Delta Truss Configuration Evaluation

3.3.1 User Accommodations Evaluation

3.3.1.1 Viewing

The delta truss Space Station configuration will provide for earth view from a pressurized area only on the sun side of the earth. This would be sufficient for most, but not all, earth sensor development. The orbit inclination would again be 28.5° .

The unpressurized sensors for solar and stellar viewing would be located along the solar cell truss with the stellar sensor at a 90° angle to the solar vector. The viewing flexibility is limited in viewing frequency of a specific target. However, it is possible to accommodate simultaneous earth, solar, and stellar viewing with this configuration.

3.3.1.2 Power

The power supplied to the user at IOC will be 60 KW continuous and at growth it will be 120 KW continuous.

3.3.1.3 Pressurized Volume

The pressurized volume at IOC provided to the user is two 22 foot modules. For growth, a total of four 22 foot modules are provided with one 44 foot module. The 44 foot module offers facility versatility in the growth phase and the two 22 foot modules offer flexibility at IOC. However, this is an issue; see Section 5.0.

3.3.1.4 Crew Time

A considerable amount of the crew's time has been allocated to the user as shown in sections 3.2.4, 3.3.4, and 3.4.4, each section pertaining to the building block configuration, delta truss configuration, and "T" configuration respectively.

3.3.1.5 External Attachments

A pallet attachment for the user is possible with this configuration.

3.3.1.6 Microgravity

The acceleration level at the modules that require low gravitational levels are assumed to be 10^{-4} g nominal. However, the effect of the modules distance from the station's c.g. has not been determined and needs to be considered for each configuration.

3.3.2 Crew Accommodations Evaluation

Due to the amount of equipment and the arrangement of the floor and ceiling, the C/C module only has the capability of having windows in one plane. It would be desirable to have windows capable of viewing all directions. Crew accommodations in the module are the WCS, a minimal galley, stored food for eight people for 22 days and a hygiene station. The accommodations are adequate.

If the manipulator is controlled from this module, the limited visibility will require additional windows or video equipment and perhaps at times, EVA crewperson to guide the manipulator.

The habitability module provides sleeping quarters, personal hygiene, medical facilities, and a galley/wardroom. The private sleeping quarter volume is adequate for sleeping, dressing, video training, and entertainment, grooming, and associated activities. It is generally preferable to have the sleeping quarters located away from noisy equipment which would disturb a sleeping crew person. The habitability module does not entirely succeed in doing this, for adjacent to the sleeping quarters is the Personal Hygiene and Medical Facility. The Personal Hygiene area contains two combination, shower/urinal/handwash facilities and a Waste Control System (WCS). The Medical Facility contains limited medical equipment and supplies and the physical conditioning equipment. To make their location in the habitability

module acceptable, the WCS and health maintenance equipment noise levels must be sufficiently low to avoid disturbing a sleeping crewperson or special accoustical isolation must be provided. The Personal Hygiene Facility coupled with a WCS in the Command and Control Module is adequate for eight crewpersons. The galley and wardroom provide facilities for use by eight crewpersons simultaneously which is adequate. The wardroom area should provide a capability for group training or entertainment.

For growth, a second similar habitability module is added to the station and the medical/physical conditioning equipment is moved to the Life Sciences Lab. The second habitability module is adequate for the increase in crew.

The habitability module is designed to permit unimpeded passage through the module. The module maintains a consistent heads-up orientation which is desirable. The floor and ceiling are offset from the module walls to allow utility equipment location. This combination renders it difficult to locate windows in these areas and consequently there are none. (It would be desirable to have windows encircling the module.)

The "delta" size and configuration has the following disadvantages:

- o About one-third of the view from any module is blocked by structure/solar arrays/other module. It is desirable to be able to view in all directions from a module.

- o An EVA crew person to reach the critical systems equipment on the "top fo the delta" must traverse considerable distance. This is not a decisive factor; however, it does add to the work, time, and complexity of the EVA. The existing manipulator system is only 50 feet in length. To reach all areas of the station will require:

- o The development of a new manipulator
- o Moveable manipulator

- o Numerous manipulators

3.3.3 Engineering Evaluation - Delta Truss

3.3.3.1 Assembly and Growth Evaluation

Two preliminary launch-by-launch sequences have been developed and are summarized in figures 3.3.3.1-1&1a. The first sequence divides the truss into three sections, each of which is launched simultaneously with the energy conversion, storage, and solar array equipment. In the second sequence, the entire IOC truss is launched on the first flight. These sequences are based on Orbiter payload bay. These sequences are based on Orbiter payload bay packaging that is plausible but optimistic. It is assumed that an Orbiter docking module is carried on all flights. All elements are installed initially in their final locations. Completion of IOC and growth capabilities is denoted by heavy vertical lines. Figure 3.3.3.1-2 illustrates the assumed packaging in the payload bay for each launch in the first sequence developed for IOC. Figure 3.3.3.1-3 illustrates the payload bay packaging for the first launch of the second sequence and the power module layout required to enable this sequence.

3.3.3.1.1 User Accommodation: Assembly and Growth

The delta provides substantial versatility in accommodations for users. The truss has large non-dedicated areas that are useable for most unpressurized payloads. It would also be possible to place additional pressurized modules along the sides of the truss, although radiators would have to be relocated. The order in which facilities are added is also relatively unconstrained after the first few launches.

3.3.3.1.2 Systems Engineering: Assembly and Growth

It is assumed that work requiring a low-gravity environment will be suspended during any station assembly operations, and therefore that this is not a discriminator. However, an earth orientation may be necessary while an Orbiter is berthed to the station depending on momentum storage capacity. If this is the case, operations requiring large amounts of power may be interrupted.

Transition efficiency is high. In the buildup scenario used, no element relocations are necessary.

There are no elements in the early phase that are discarded in later stages. Assembly will require the full capability of the Orbiter RMS. A second RMS or a handling and positioning aid will be needed in some steps. Note that the RMS reach analysis in section 3.3.4.2 assumes a large manipulator on the station at an early point in the buildup in lieu of a handling and positioning aid. Substantial EVA and/or RMS operations will be necessary primarily for joining the truss sections in the first launch sequence or for installation of the power equipment to the existing truss in the second launch sequence. Both these functions appear possible with the joining of truss sections being judged the more difficult. It is noted that joining truss sections is required in either scenario in the growth phase.

Removal of a module does not affect the structural characteristics of the station. If the pressure loads between modules are carried through the truss, removal is a simple process of disconnecting internal and external umbilicals, closing hatches, and depressurizing and retracting the intermodule connectors. If the loads are carried directly between modules, the task may be more difficult depending on the design of the connectors.

BUILDUP SEQUENCE

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Configuration DELTA, IOC Truss in 3 launches

Date 12/12/83

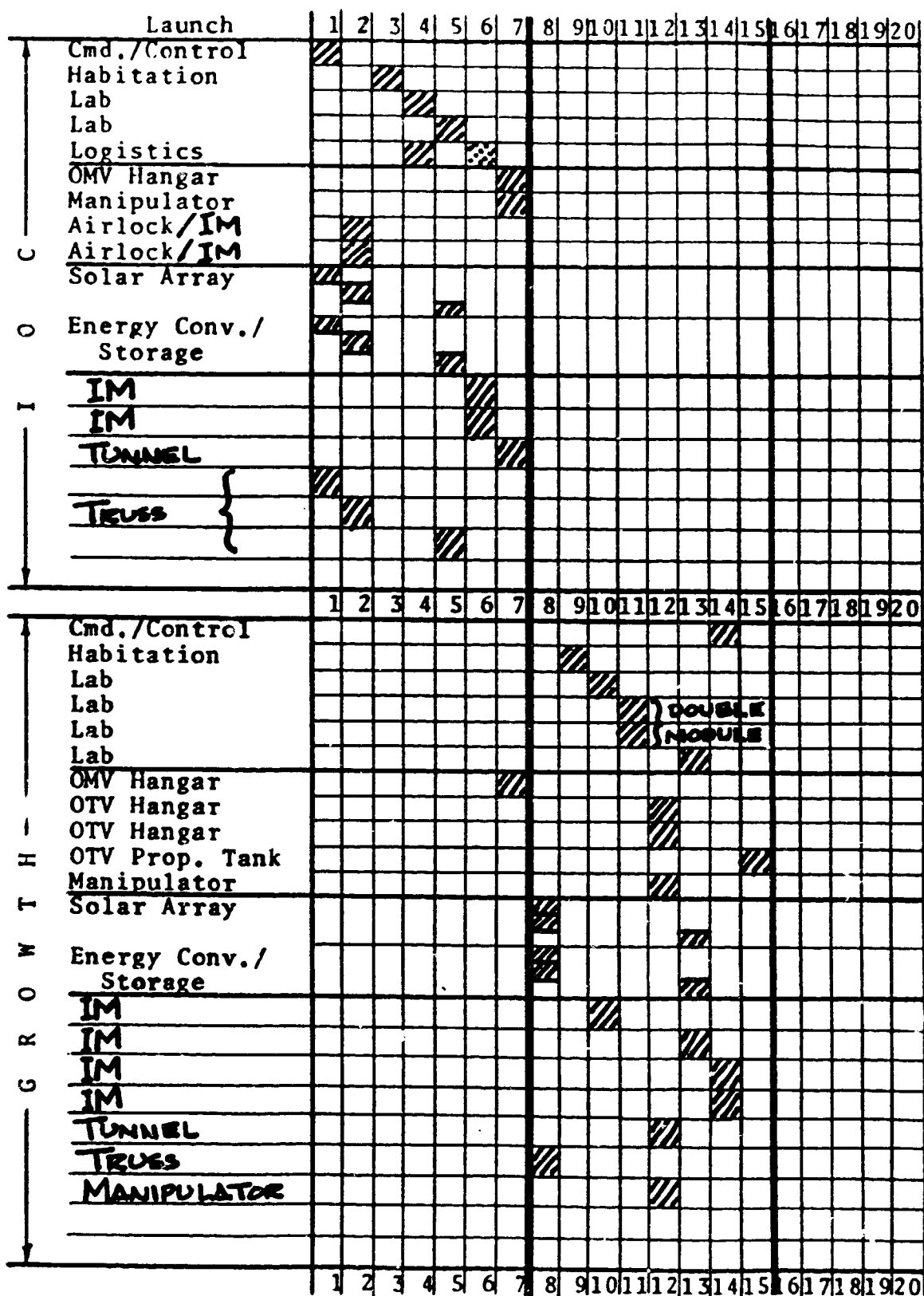


Figure 3.3.3.1-1

BUILDUP SEQUENCE

ORIGINAL
OF POOR QUALITY

Configuration DELTA, IOC Truss in 3 launches

Date 12/11/83

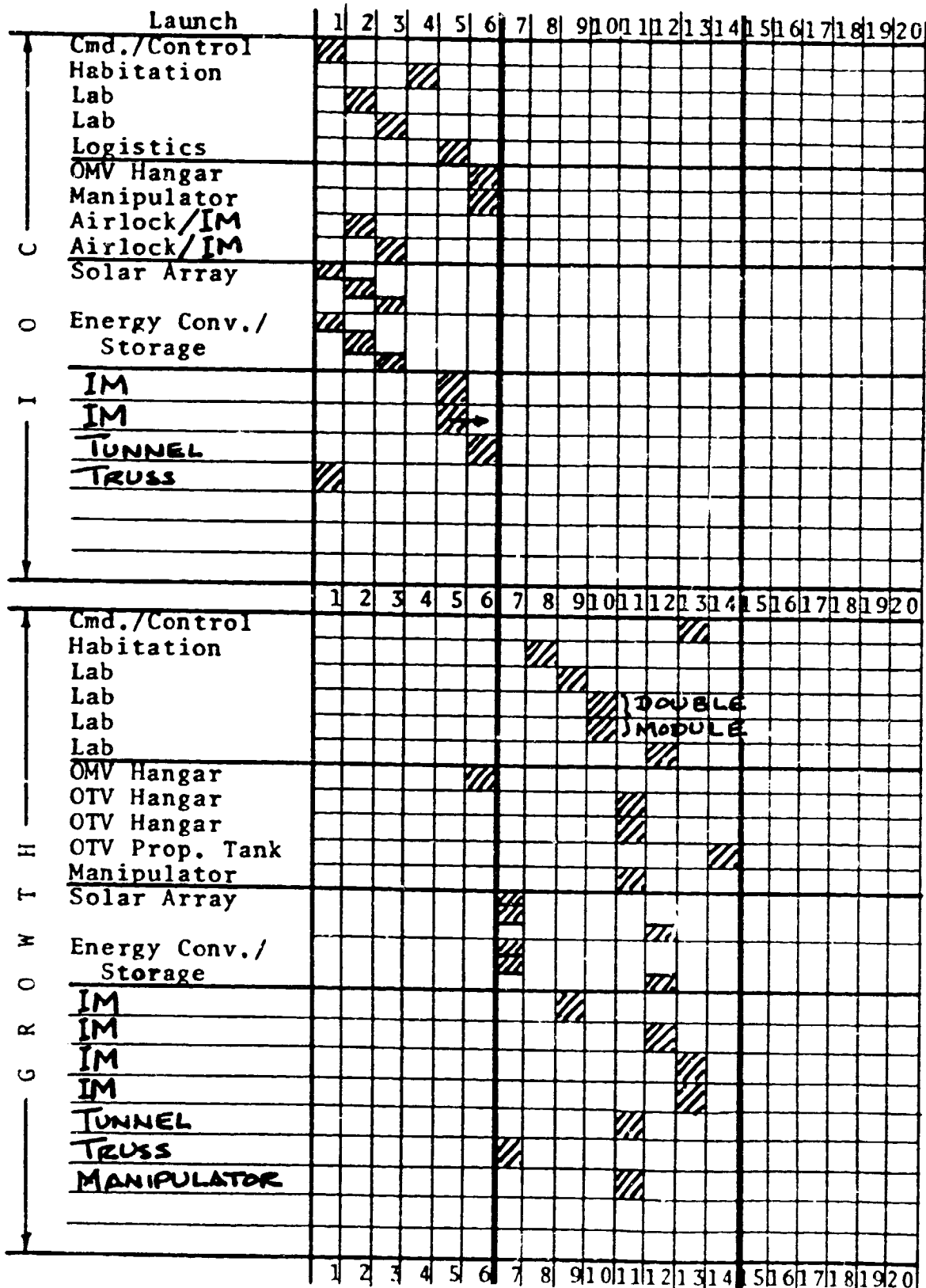


Figure 3.3.3.1-1a

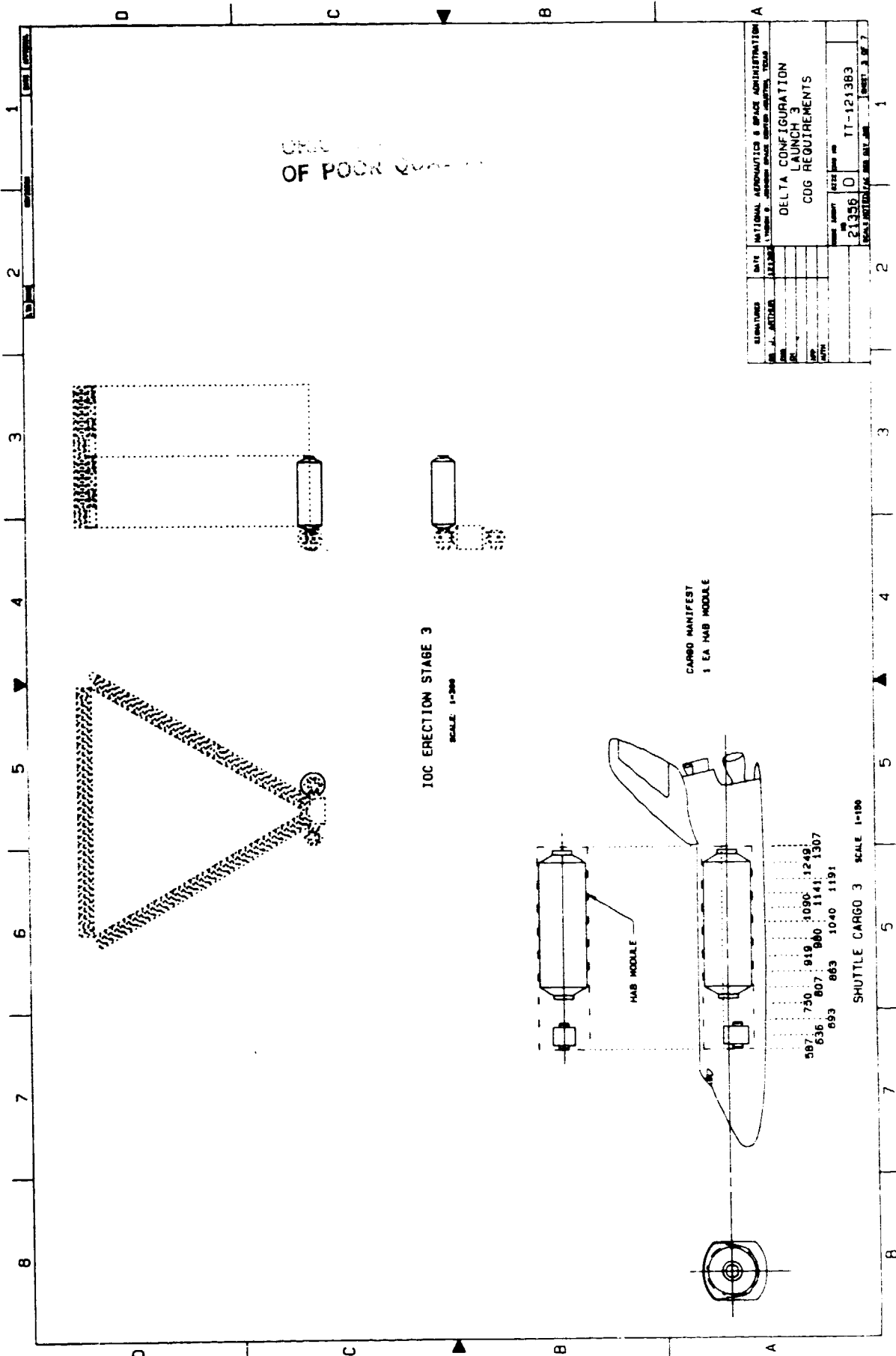


Figure 3.3.3.1-2c

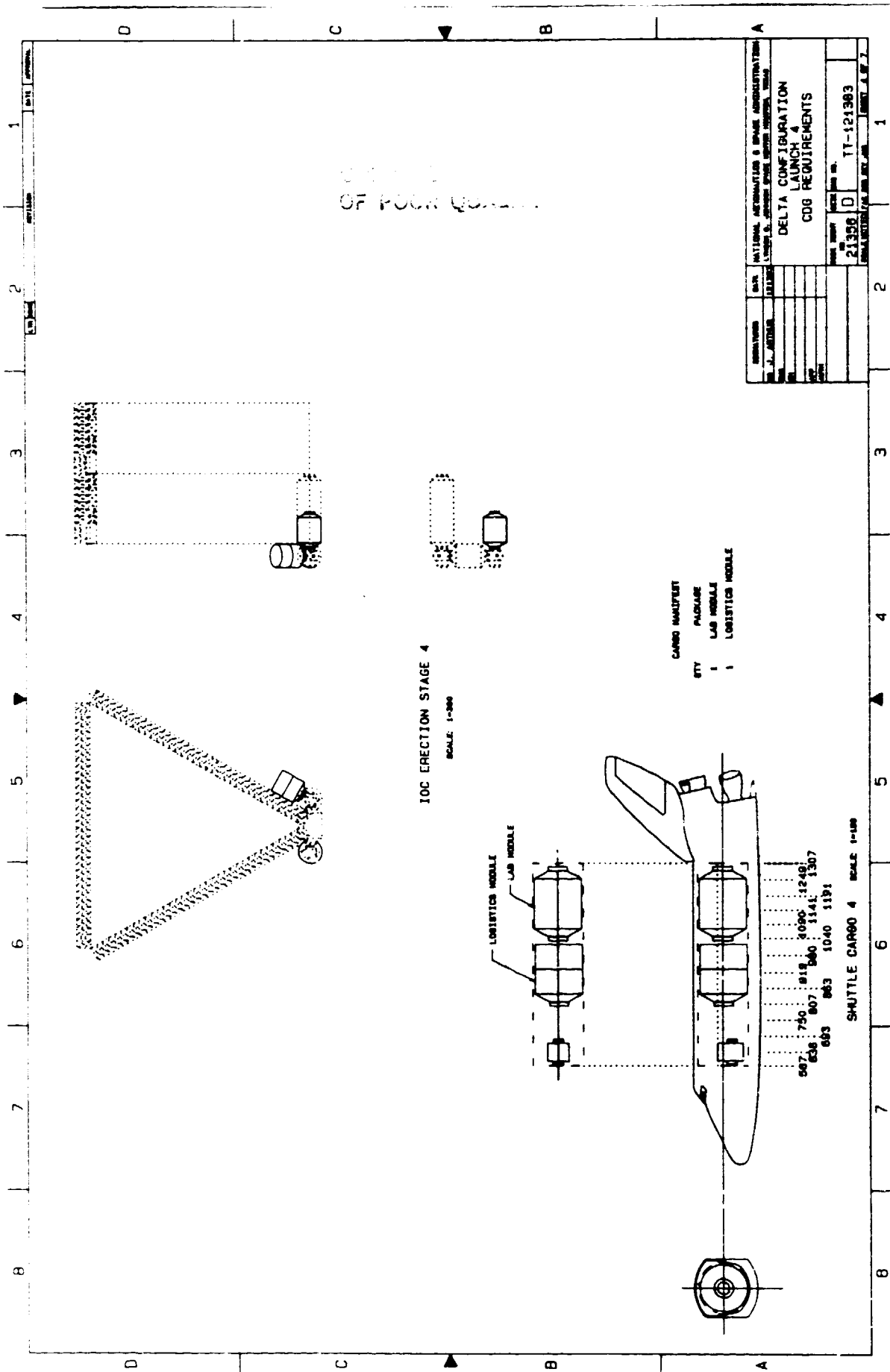
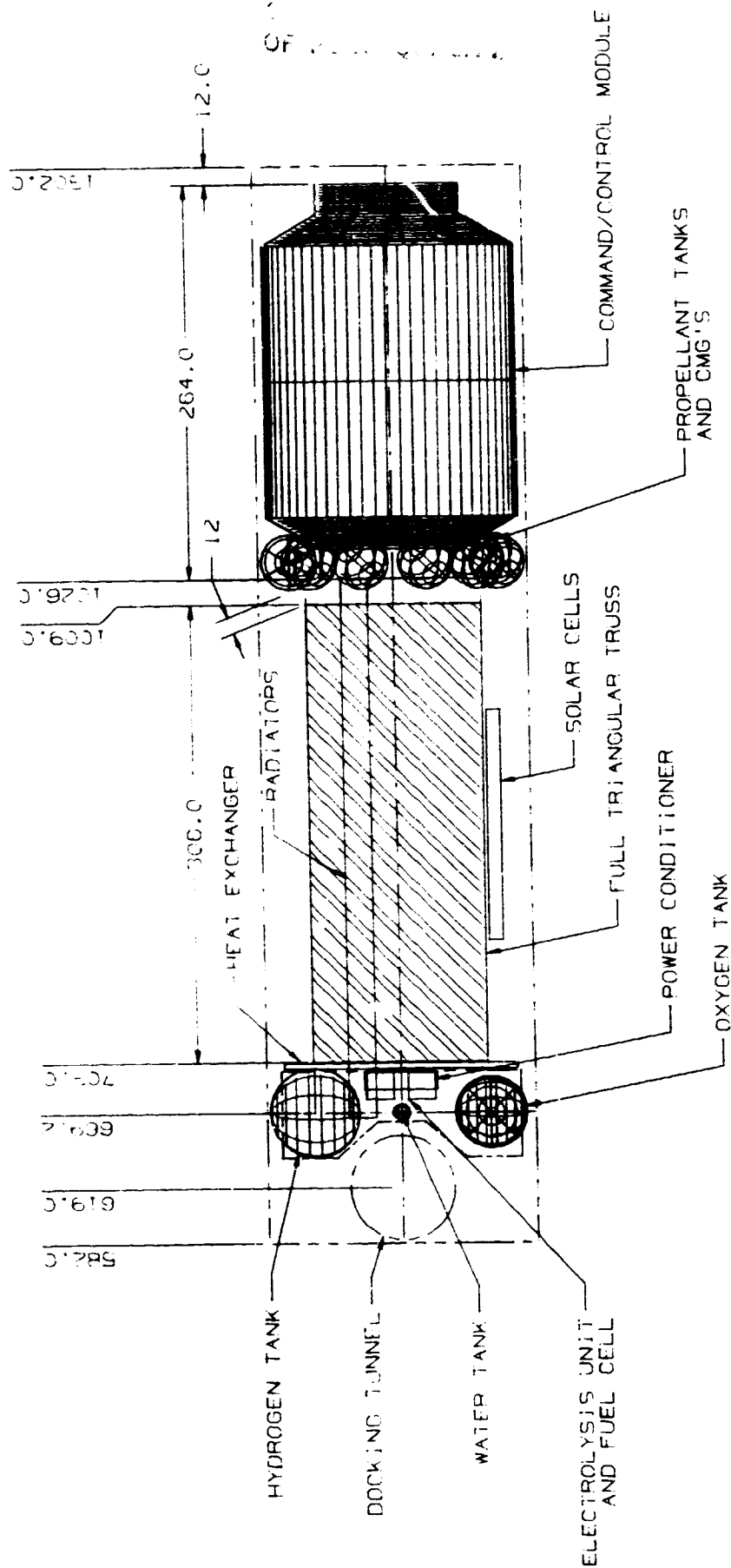


Figure 3.3.3.1-2d

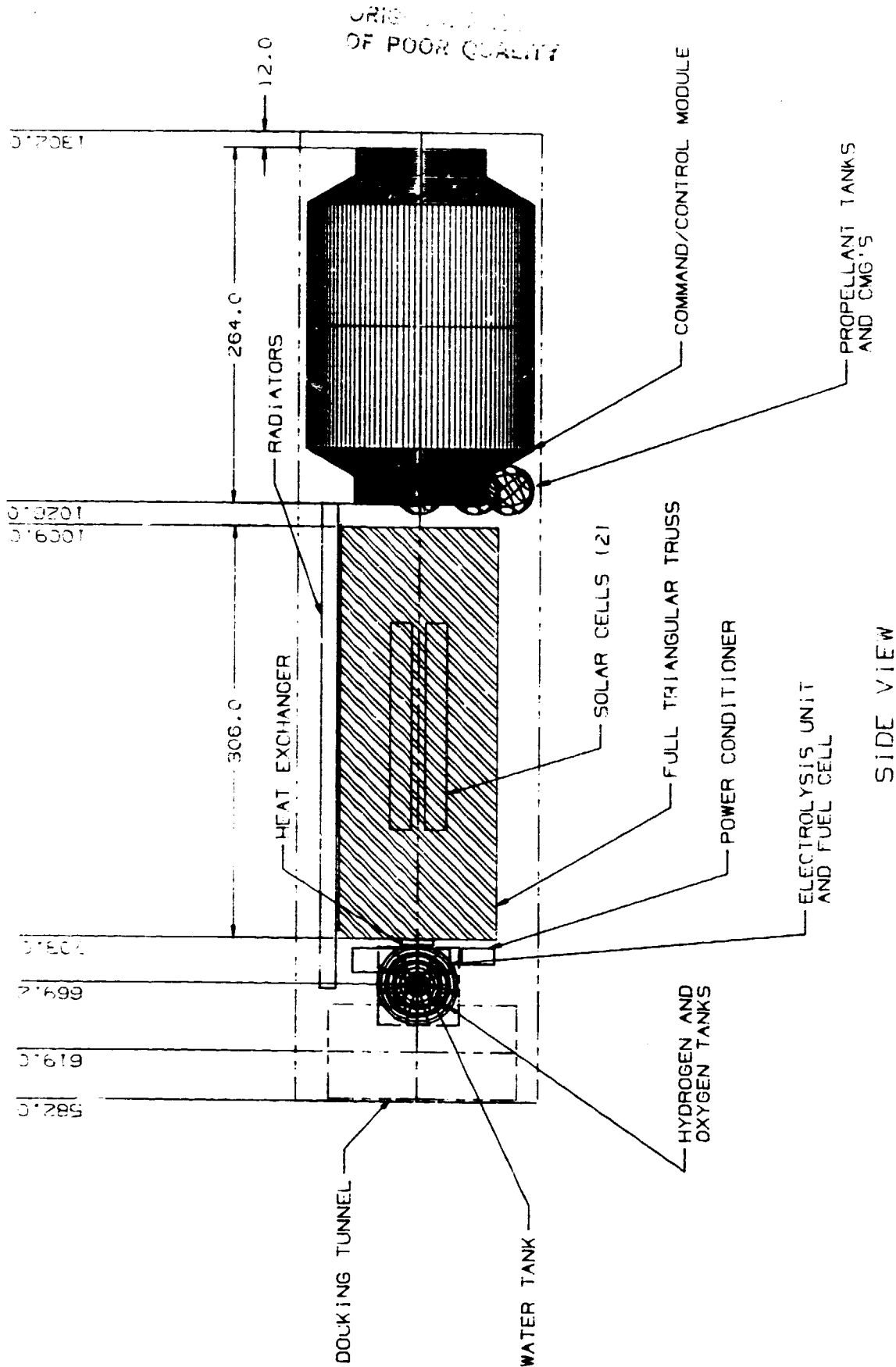


PLAN VIEW

FULL TRIANGULAR TRUSS

LAUNCH I

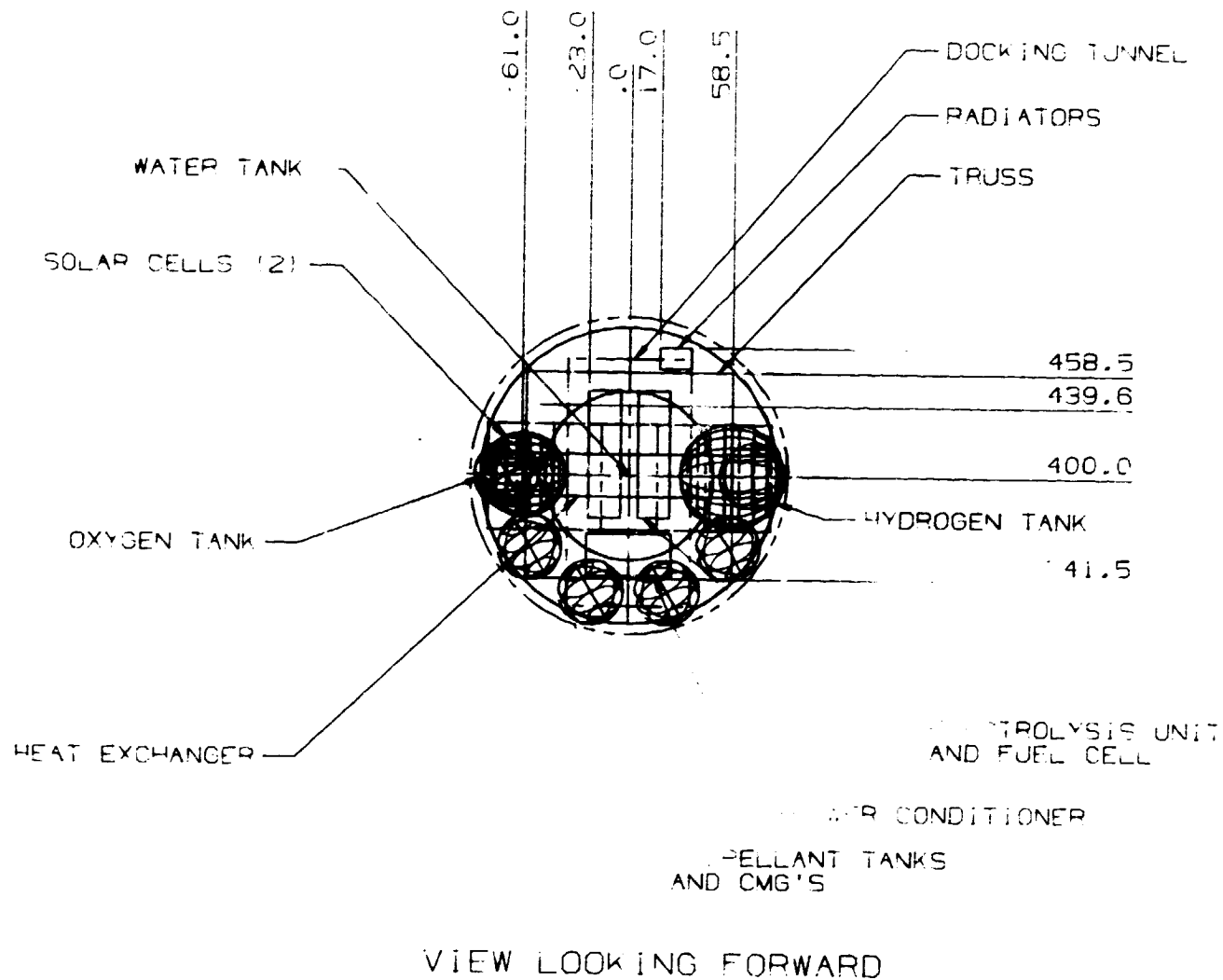
Figure 3.3.3.1-3a



FULL TRIANGULAR TRUSS
LAUNCH 1

Figure 3.3.3.1-3b

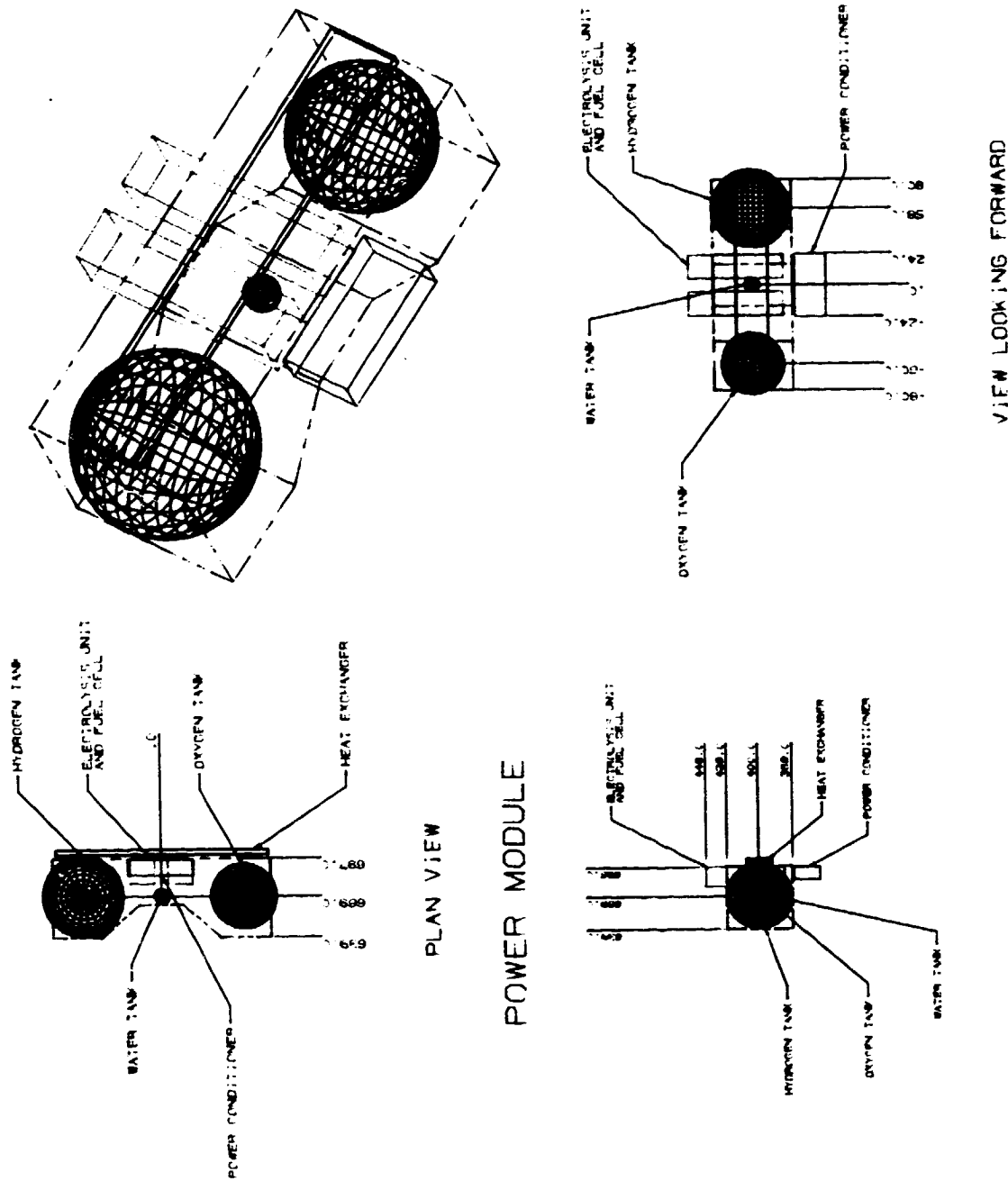
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FULL TRIANGULAR TRUSS LAUNCH 1

Figure 3.3.3.1-3C

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POWER MODULE

POWER MODULE

Figure 3.3.3.1- 3d

Two Orbiter berthing ports are available at IOC and four in the growth configuration. Sixteen other ports are available for logistics modules and other temporary payloads, since each IM has five ports.

3.3.3.1.3 Programmatics: Assembly and Growth

The first buildup sequence reaches IOC in seven launches. Redundancy of essential systems is reached in three launches after which the station could be permanently manned. Lack of a LM or logistics module would limit both crew size and useful activity. The fourth launch supplies both of these modules and the station could do useful work from that time. The second buildup sequence, in which the entire truss is launch at one time, would still require three launches before permanent manning but reaches IOC in six.

The reference scenario requires 15 flights to reach full growth capability. The alternate buildup scheme could reduce this by one flight. Efficient hangar design and packaging might save another flight. Full capability might therefore be achieved in 13 launches.

3.3.3.1.4 Safety: Assembly and Growth

As configured (see figure 2.3-2), the OTV propellant storage facility is located very near the inhabited modules. This location was selected for its proximity to the station center of mass to minimize moment of inertia variations. Alternative locations appear possible but less desirable. Isolation of a hazardous condition, such as a spill of a toxic substance, can be done with little difficulty. Since there are two routes to each module, any one can be isolated without significant disruption of other activities.

3.3.3.2 Structural Dynamics and Control Evaluation

3.3.3.2.1 Delta Flight Modes

The Delta truss configuration has been designed to fly primarily in a solar inertial flight mode; however, it can also fly in the earth fixed flight mode (LVLH). See figure 3.3.3.2-1. The solar array is currently sized for the solar inertial flight mode. Electrical power produced in the earth fixed flight mode (LVLH) would be approximately 55% of the power produced in the primary flight mode. The prime use of the LVLH mode is during orbit maintenance. The RCS engines are located only on one end of the module string, thus for Hohmann orbit transfers the station needs to fly in a earth fixed mode. There also may be user requirements that can be easily met with an earth fixed flight mode.

In the solar inertial flight mode, the Delta flies with its Y principal axes perpendicular to the orbit plane (see figure 3.3.3.2-1) and with the solar array aligned to minimize β cosine power loss by rotation about the Y-principal axis. The solar array size is increased to account for β cosine loss. The mass properties of the Delta growth result in a principal axes that is approximately 24° from the plane of the solar array, and the mass properties of the Delta IOC results in a principal axes that is approximately 20° from the plane of the solar array. The Delta flight orientation yaws 180° every sun season (every time the sun crosses the plane of the equator-twice a year to maximize power generation).

The Delta can also fly in an earth fixed (see figure 3.3.3.2-2) LVLH mode rolled to correct the solar β misalignment. In this flight mode, the Delta is pitched in the orbit plane to achieve a TEA. The CMG's control the resulting cycle torque disturbances. This mode is used for orbit maintenance since the RCS engines are co-located on one side of the Delta.

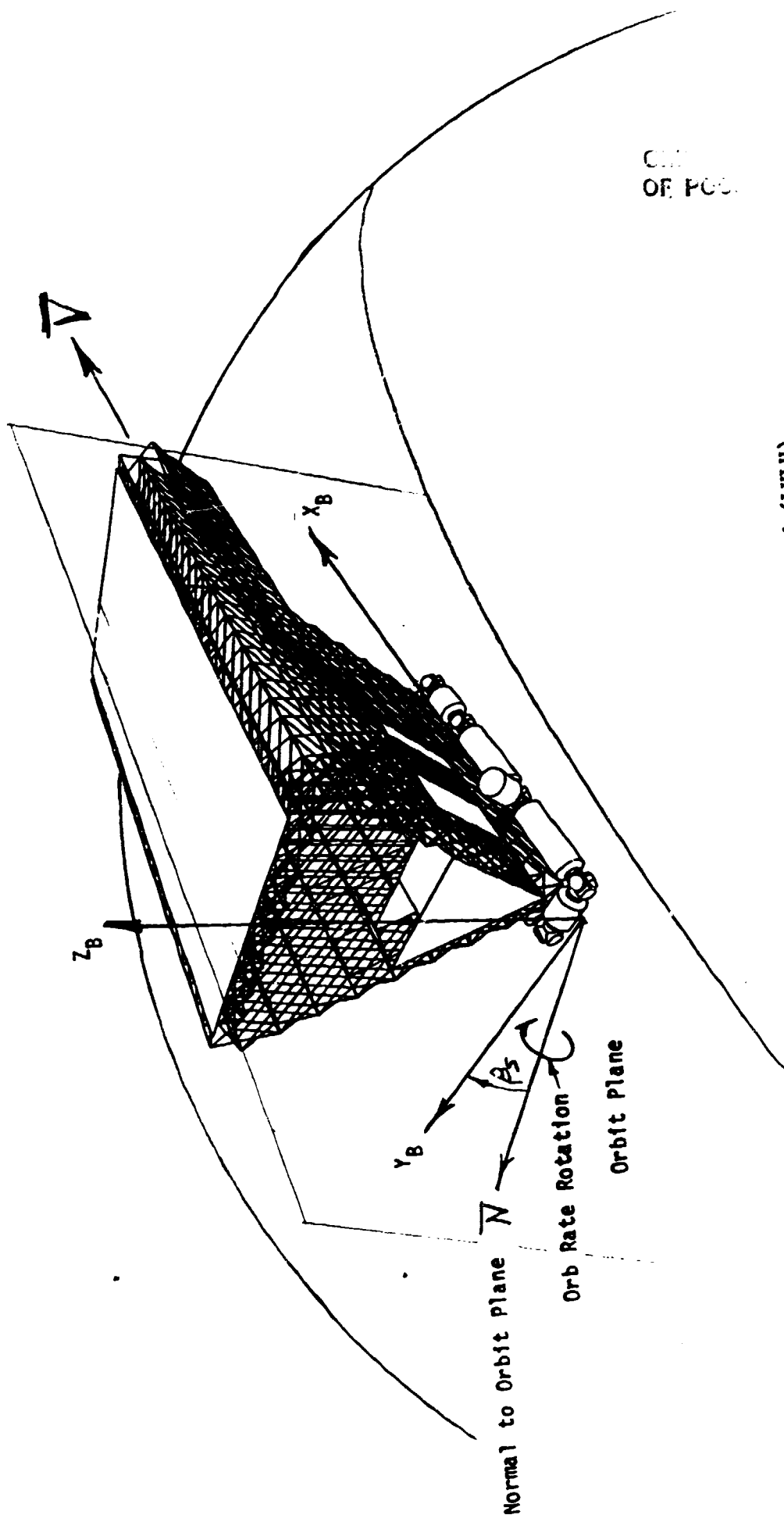


Figure 3.3.3.2-1 Delta Flight Orientation - Earth Fixed (LVLH)



3.3.3.2.2 On-Orbit Disturbance - Gravity Gradient

Operation in low earth orbit (270 NM) provides exposure to significant gravity gradient disturbances. These are on the order of 70-foot-pounds for the Delta Space Station. While relatively insignificant from a controllability point of view, the extreme time span of the Space Station mission makes these significant drives for "cost-of-ownership," unless steps are taken to minimize their influence.

3.3.3.2.3 Aerodynamic Torque Disturbance

In addition to gravity gradient torques, the aerodynamic torques can produce secular momentum accumulation. Detailed simulation of the aerodynamic disturbances for the Delta configuration has been conducted. However, the asymmetric effect of the diurnal atmosphere variation has been neglected for this analysis. In the earth fixed mode, the large areas of the solar arrays are never directly exposed to the free molecular flow particule velocity for the Delta, hence, only effects of the modules and truss edges are involved.

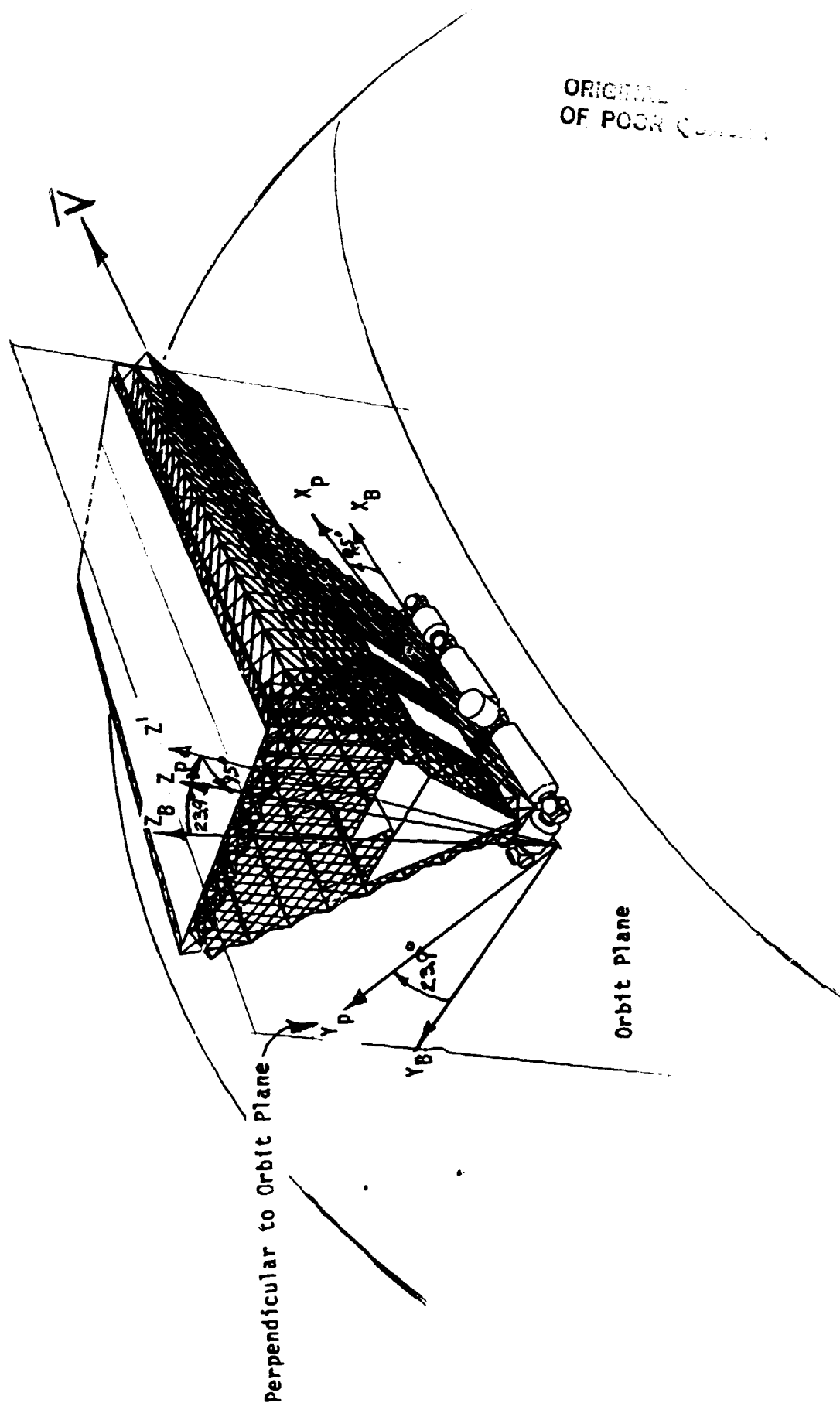


Figure 3.3.3.2-2 Delta Flight Orientation - Solar Inertial

3.3.3.2.4 Mass Properties Management

A mass properties management scheme must be employed in the Space Station design in order to enhance the flight performance.

Adjust Delta mass properties such that the I_{yy} principal axes is approximately 20° from the plane of the solar array. The mass properties for the Delta in both the IOC and growth stages are shown below:

	<u>IOC</u>	<u>GROWTH</u>	
IXXP	1.6 E 7	2.82 E 7	slug-ft ²
IYYP	1.7 E 7	8.32 E 7	slug-ft ²
IZZP	.77 E 7	6.96 E 7	slug-ft ²
θ_x^*	21.8°	23.9°	
θ_y^*	25.1°	- .95°	
θ_z^*	4.3°	0°	
R_x^*	39.0	67.3	ft
R_y^*	-8.7	-4.7	ft
R_z^*	22.3	21.4	ft
Wgt	258.6K	662.0K	lbs

* Euler angles, rotate from geometric axes to principal axes with rotation order θ_x , θ_y , and θ_z . R_x , R_y , and R_z are center of mass vector. IXXP, IYYP, IZZP are the principal inertias.

3.3.3.2.5 Momentum Storage Requirements

Momentum storage requirements are based upon the peak cyclic momentum variations, and the attitude control system philosophy regarding the amount of reliance on the CMG's for attitude maneuvers and absorption of large impulsive disturbances (i.e, max between CMG torque impulse). Peak cyclic momentum storage due to the gravity gradient is presented below.

Due to the time available for this study, the momentum storage requirements was sized only for the nominal flight conditions involving attitude hold.

PEAK CYCLIC GRAVITY GRADIENT MOMENTUM (FT-LB-SEC)

Flight Mode	IOC	Delta Growth
Inertial	9,000	36,000
Earth Fixed	13,000	25,000

3.3.3.2.6 Orbital Maintenance Impulse Requirements

Orbital maintenance impulse was determined using the NASA neutral atmosphere (SP-8021) density at 270 NM and average aerodynamic properties to compute the drag impulse. The NASA neutral atmosphere is considered to be the worst long-term atmosphere applicable to a 90-day resupply cycle. Short term maximum conditions should be used for RCS engine magnitude sizing.

The disturbance simulation used a dynamic pressure of .99905E-6 lb/ft².

Summary results for the three configurations are shown below:

DRAG IMPULSE PER ORBIT

(LB-SEC/ORBIT)

Configuration	Delta	
Flight Mode	IOC	Growth
Inertial	240	385
Earth Fixed	120	120

Using the data shown above worst case resupply propellant for altitude maintenance was calculated and reported in the table below. This assumes that the orbit is not allowed to deviate from 270 NM.

90-DAY RESUPPLY PROPELLANT FOR ALTITUDE MAINTENANCE FOR 270 NM

LBS - (Normalized to: Isp = 220 sec)

Configuration	Delta	
Flight Mode	IOC	Growth
Inertial	1,500	2,900
Earth Fixed	750	750

3.3.3.2.7 RCS Firing Frequency

Detailed flight dynamic simulations of the Delta configuration shows that the Delta configuration can be trimmed so that there is no secular torque momentum accumulation per orbit. Thus, no RCS firing are required for CMG desaturation. The Delta configuration can achieve a minimal RCS altitude maintenance firing frequency of once every 90-days chosen to coincide with STS resupply. This will be particularly attractive to long term low "g" scientific experiments and manufacturing processes. Altitude loss will be less than seven miles in 90-days.

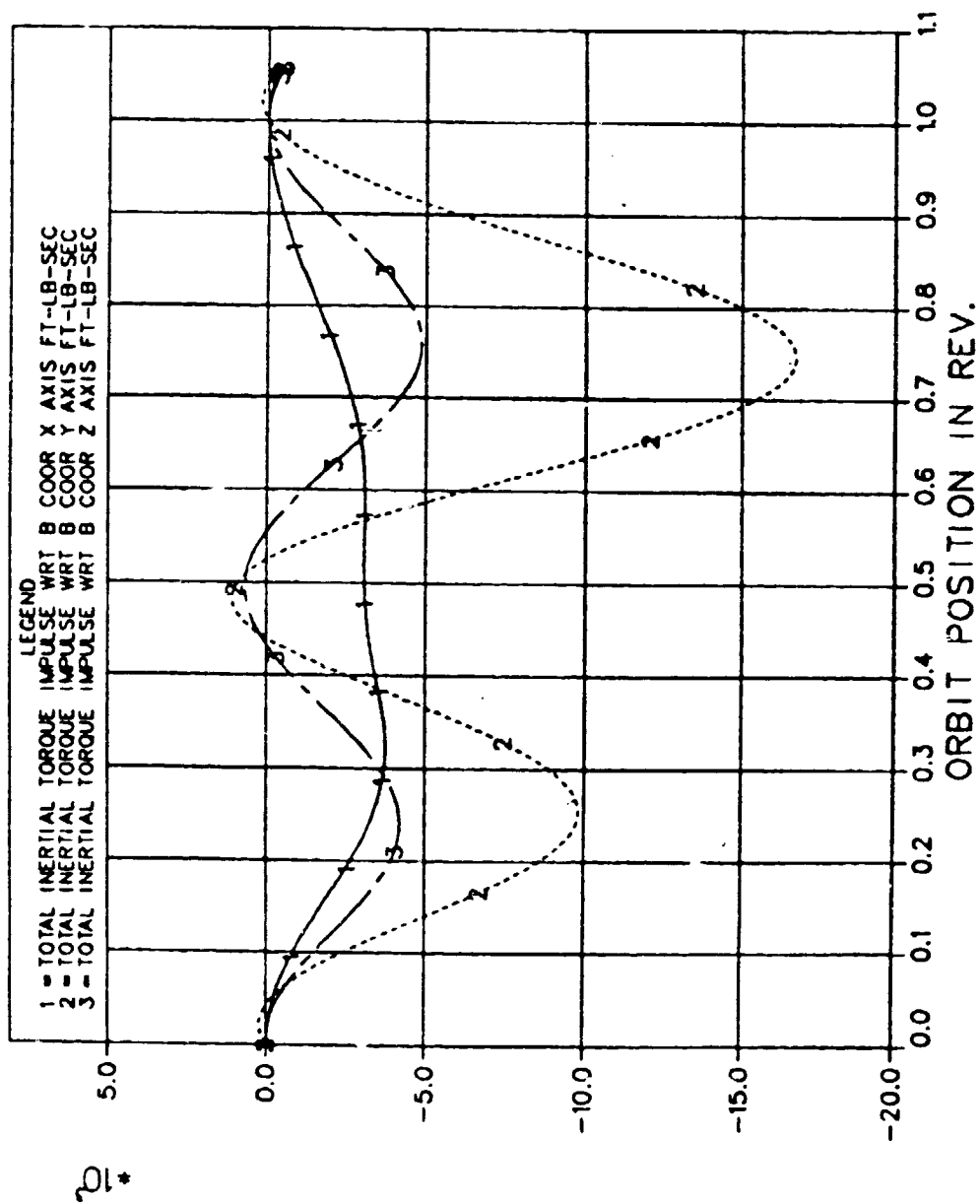
3.3.3.2.8 Results of On-Orbit Flight Dynamics for Delta IOC

The results of the on-orbit flight dynamics of the Delta IOC solar inertial mode are shown in figures 3.3.3.2-3 through 3.3.3.2-8. Figure 3.3.3.2-3 inertial torque impulse history of the Delta-IOC for one orbit. The torque impulse curves show no secular components at the end of an orbit. The cyclic momentum storage requirement is 9,000 ft-lbs-sec. Figures 3.3.3.2-4 shows the resultant aero force drag impulse history for one orbit. The total drag impulse per orbit is 240 sec. Figure 3.3.3.2-5 shows the resultant drag force history which peaks at about .053 lbs. Figure 3.3.3.2-6 shows the gravity gradient torque history which peaks at 15 ft-lbs. Figure 3.3.3.2-7 shows the aerodynamic torque history which has a peak pitch torque of 4.3 ft-lbs. Figure 3.3.3.2-8 shows the resultant torque history which has a peak pitch torque of 19.5 ft-lbs.

3.3.3.2.9 Results of On-Orbit Flight Dynamic for Solar Inertial Flight Mode

The results of the on-orbit flight dynamic of the Delta IOC solar inertial mode are shown in figures 3.3.3.2-9 through 3.3.3.2-14. Figure 3.3.3.2-9 shows inertial torque impulse history of the Delta growth for one orbit. The cyclic momentum storage requirement is 36,000 ft-lbs secs. Figure 3.3.3.2-10 shows the resultant aero drag impulse history for one orbit. The total drag impulse per orbit is 380 sec. Figure 3.3.3.2-11 shows the resultant drag force history which peaks at about 0.1 lbs. Figure 3.3.3.2-12 shows the gravity gradient torque history which peaks at 70 ft-lbs. Figure 3.3.3.2-13 shows the aerodynamic torque history which has a peak pitch torque of 8.0 ft-lbs. Figure 3.3.3.2-14 shows the resultant torque history which has a peak pitch torque of 76.0 ft-lbs.

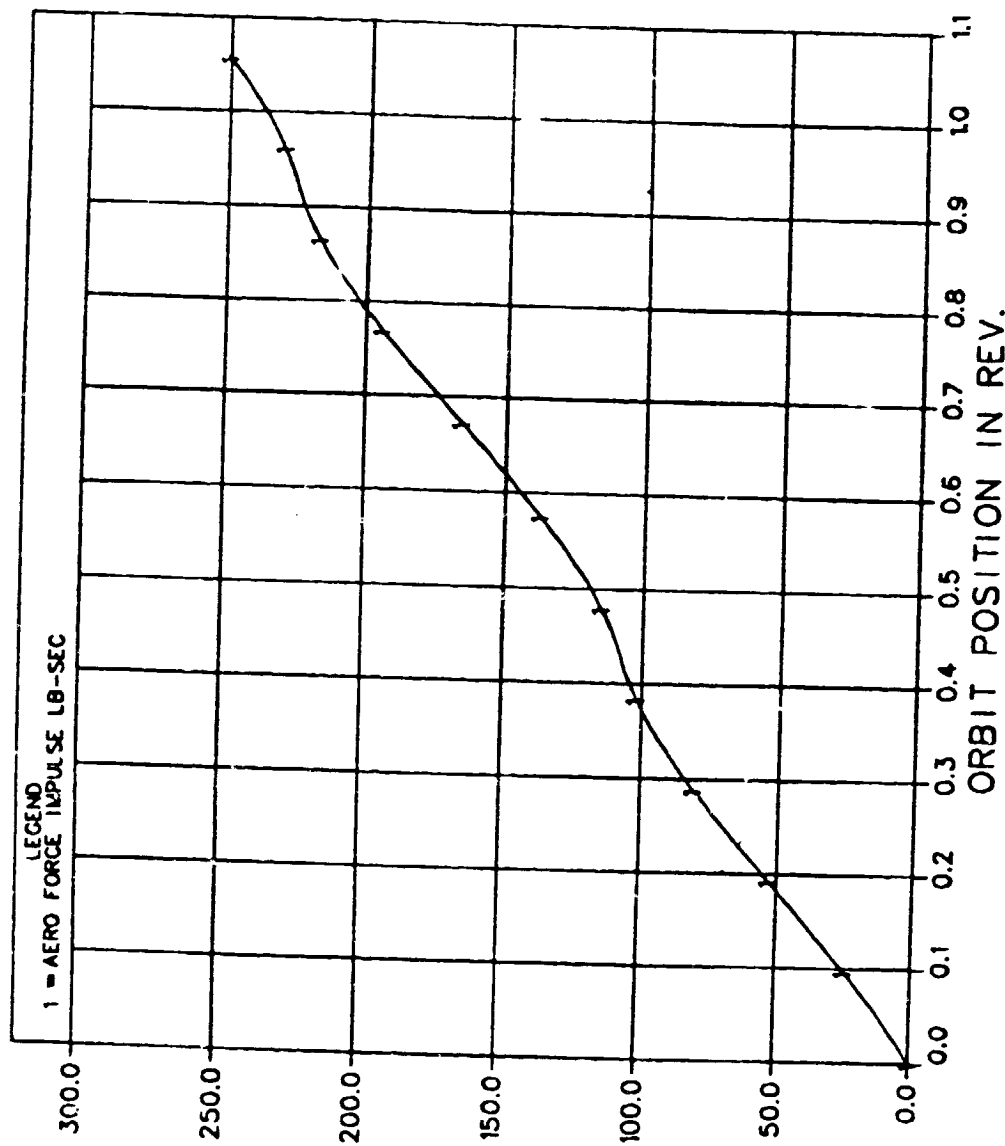
DELIOC, INCL=0, SUN=-22.5, DELTA AT PRIN, SOLAR INERTIAL



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Figure 3.3.3.2-3 Delta Momentum Accumulation Time History

DELIOC, INCL=0, SUN=-22.5, DELTA AT PRIN, SOLAR INERTIAL

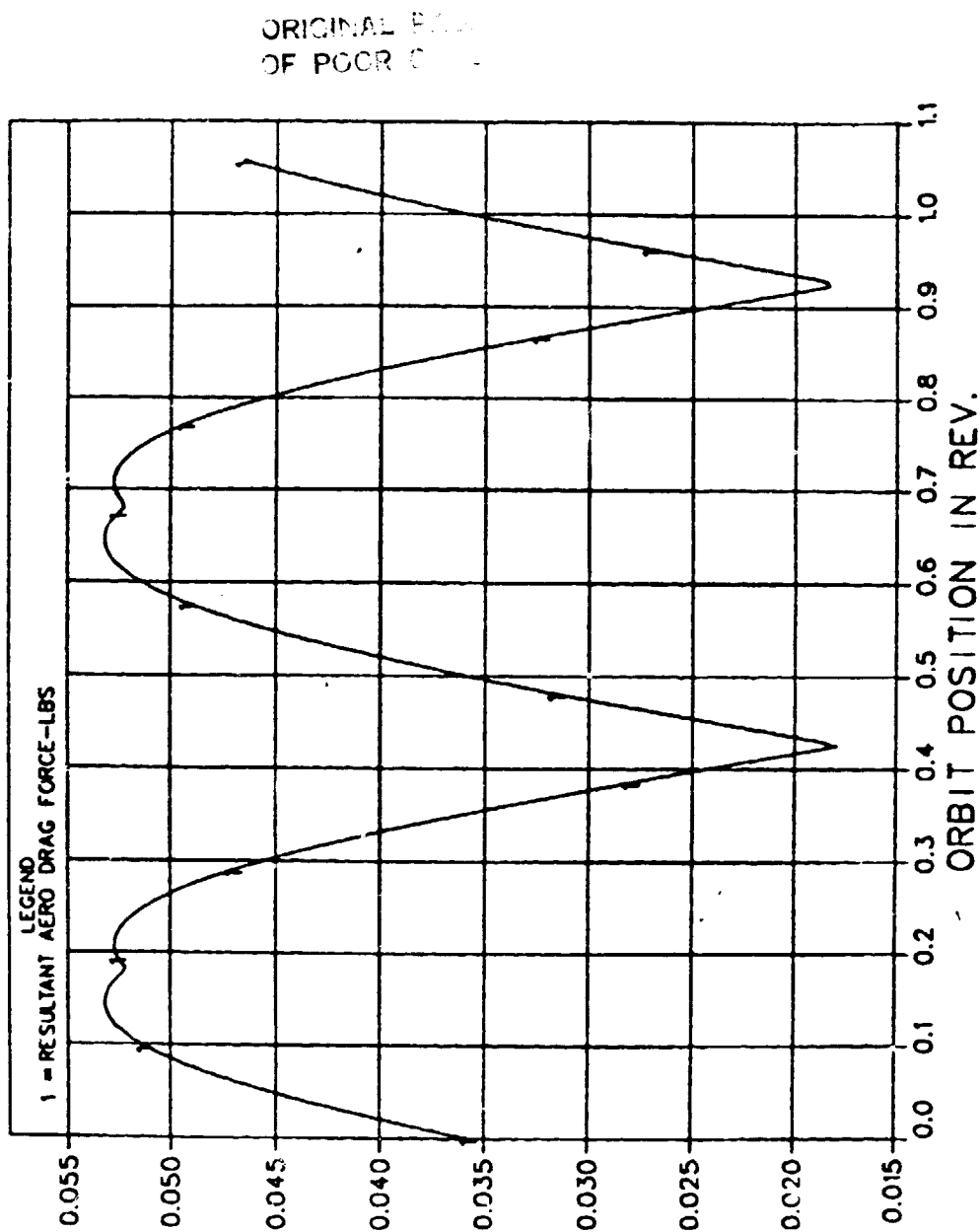


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Figure 3.3.3.2-4 Delta-IOC Aerodynamic Drag Impulse Time History

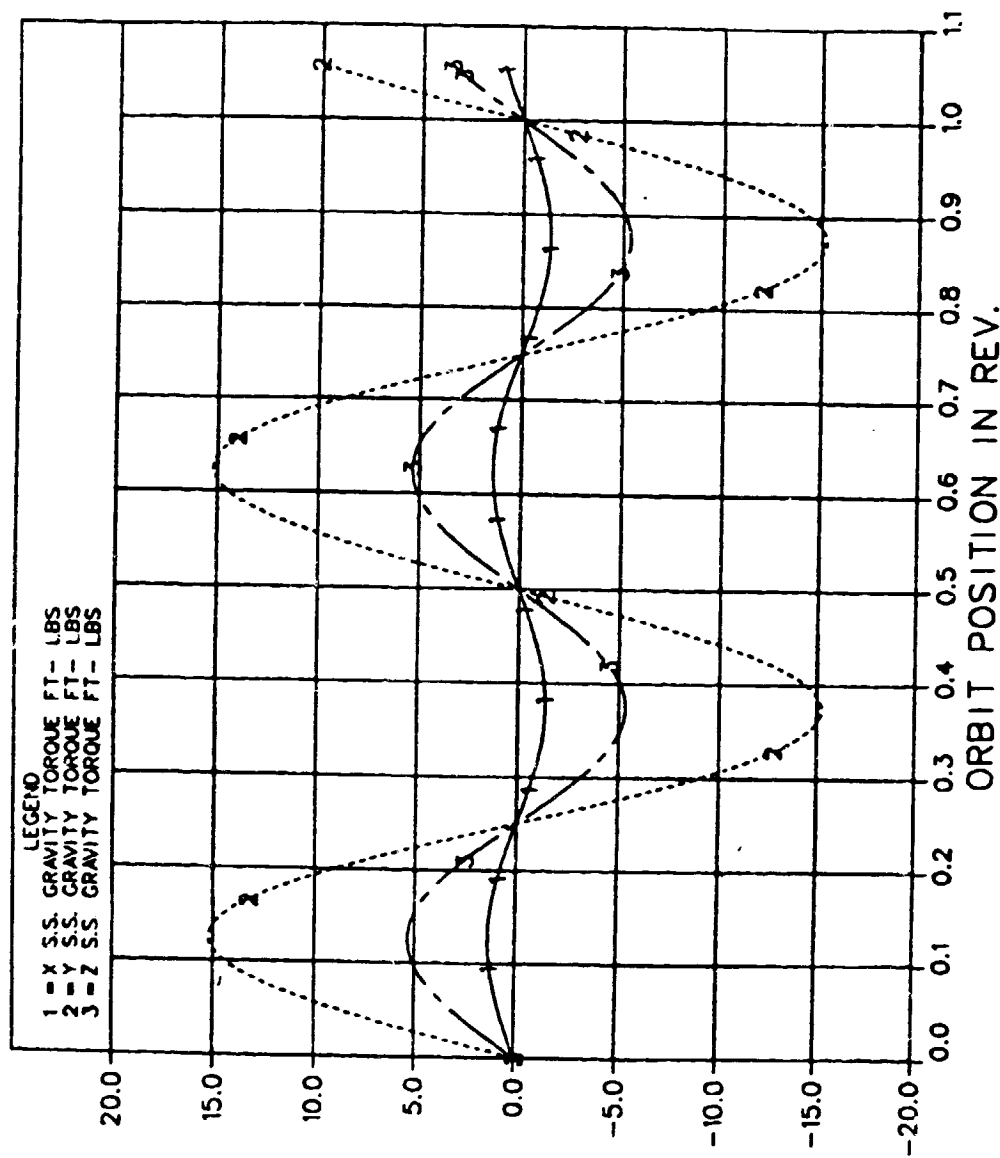
DELIOC, INCL=0, SUN=-22.5, DELTA AT PRIN, SOLAR INERTIAL



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Figure 3.3.3.2-5 Delta-IOC Total Aerodynamic Drag Force Time History

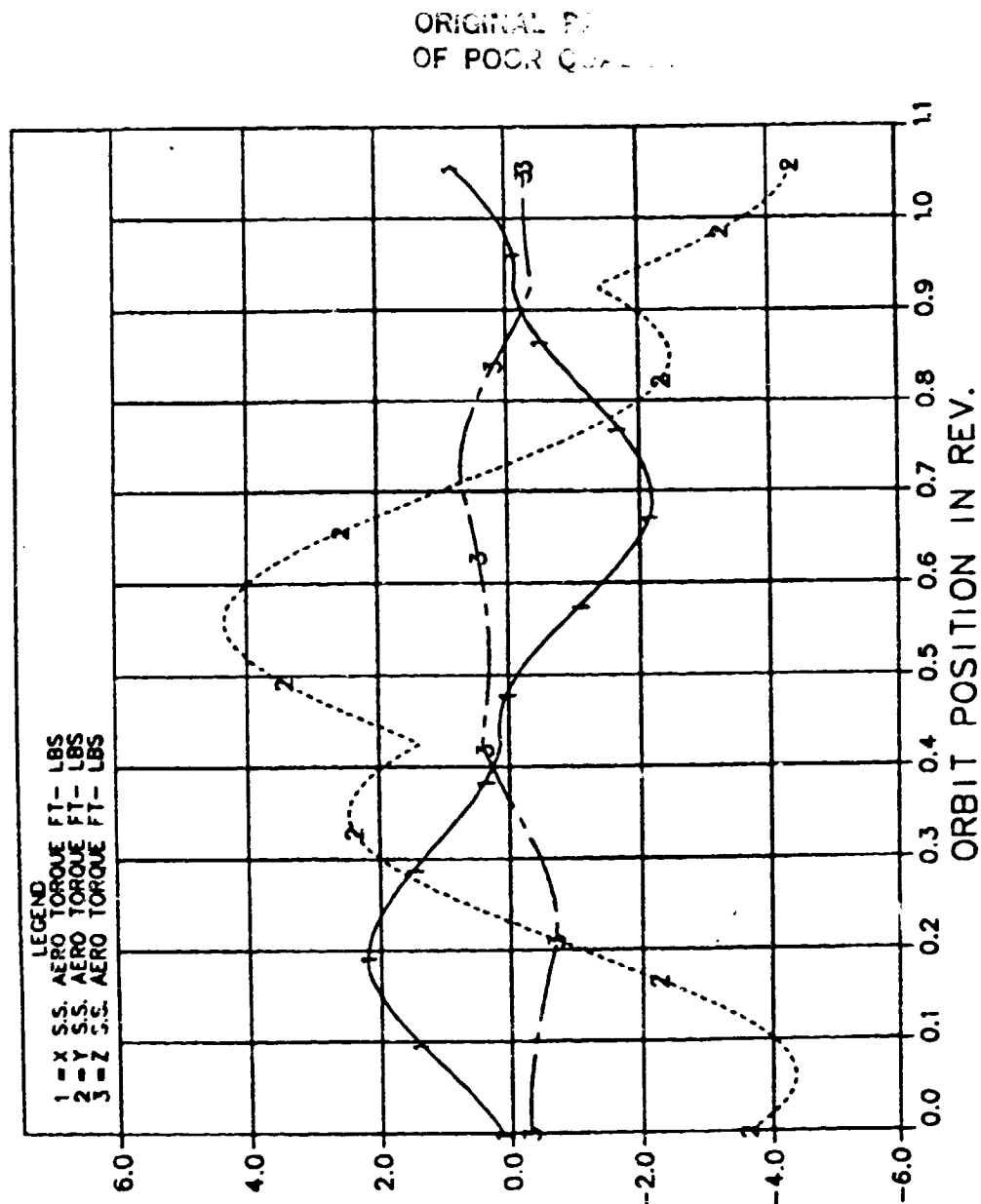
DELI OC, INCL=0, SUN=-22.5, DELTA AT PRIN, SOLAR INERTIAL



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Figure 3.3.3.2-6 Delta-IOC Total Gravity Gradient Torque Time History

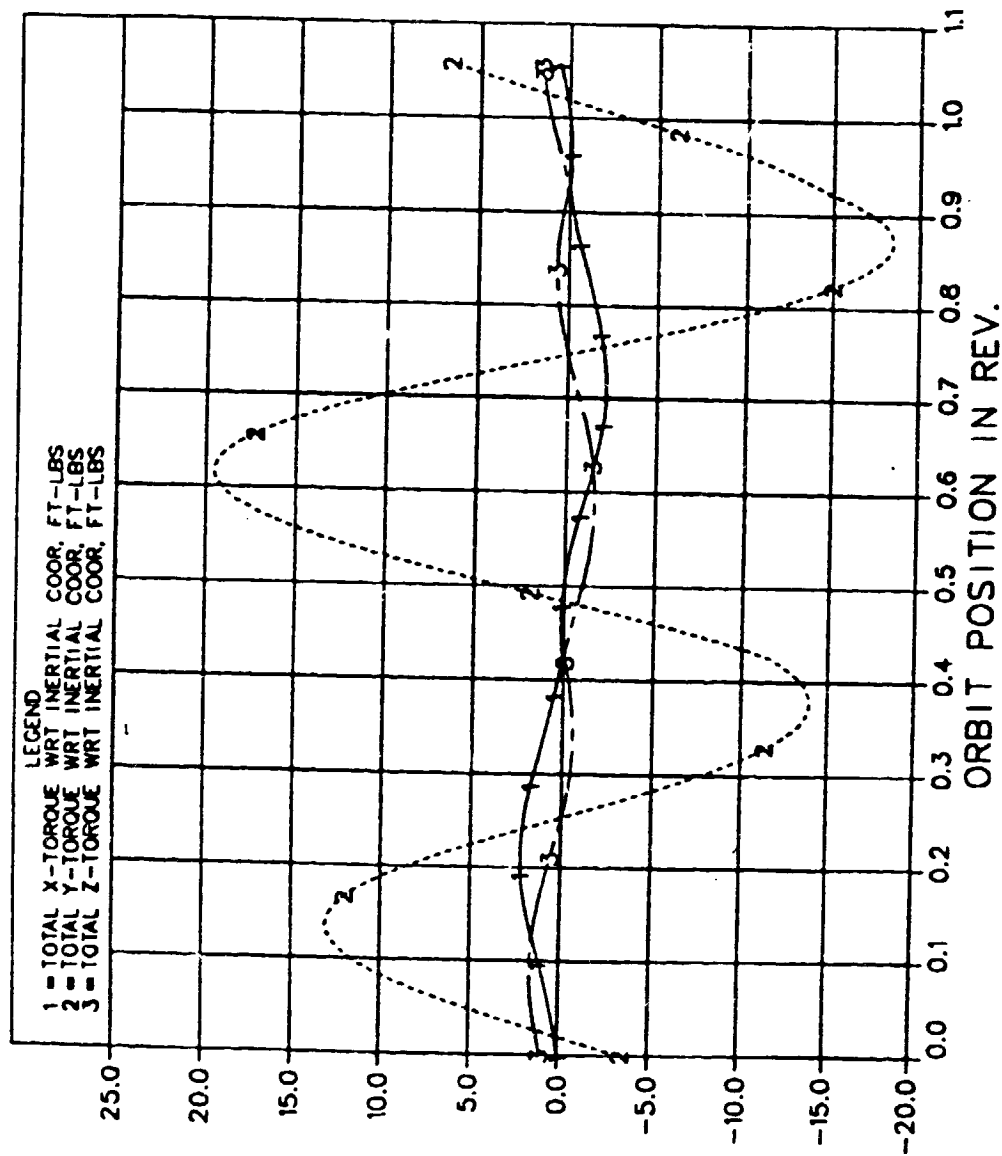
DELIOC, INCL=0, SUN=-22.5, DELTA AT PRIN, SOLAR INERTIAL



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Figure 3.3.3.2-7 Delta-IOC Aerodynamic Torque Time History

DELIOC, INCL=0, SUN=-22.5, DELTA AT PRIN, SOLAR INERTIAL

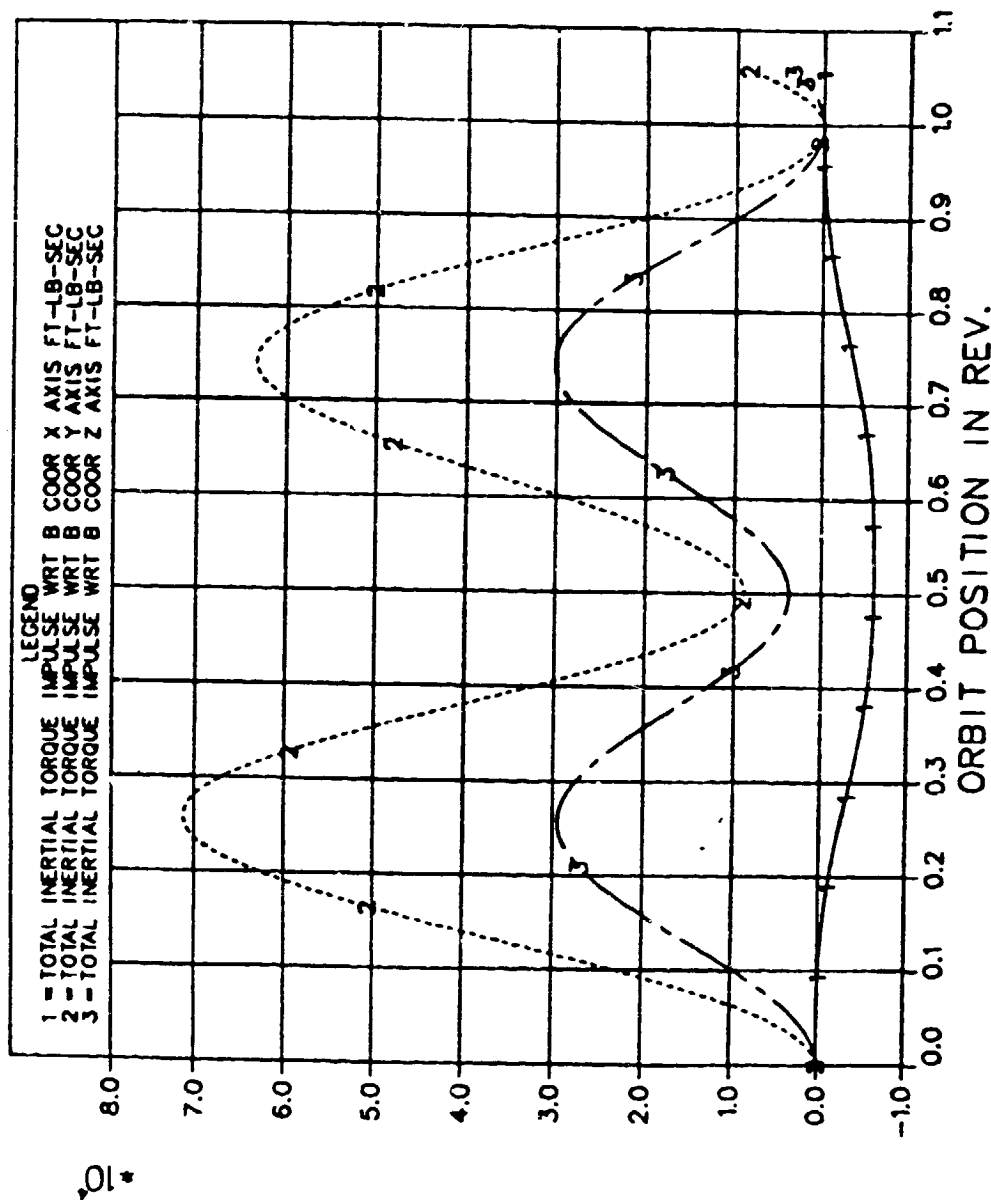


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Figure 3.3.3.2-8 Delta-IUC Total External Disturbance Torque Time History

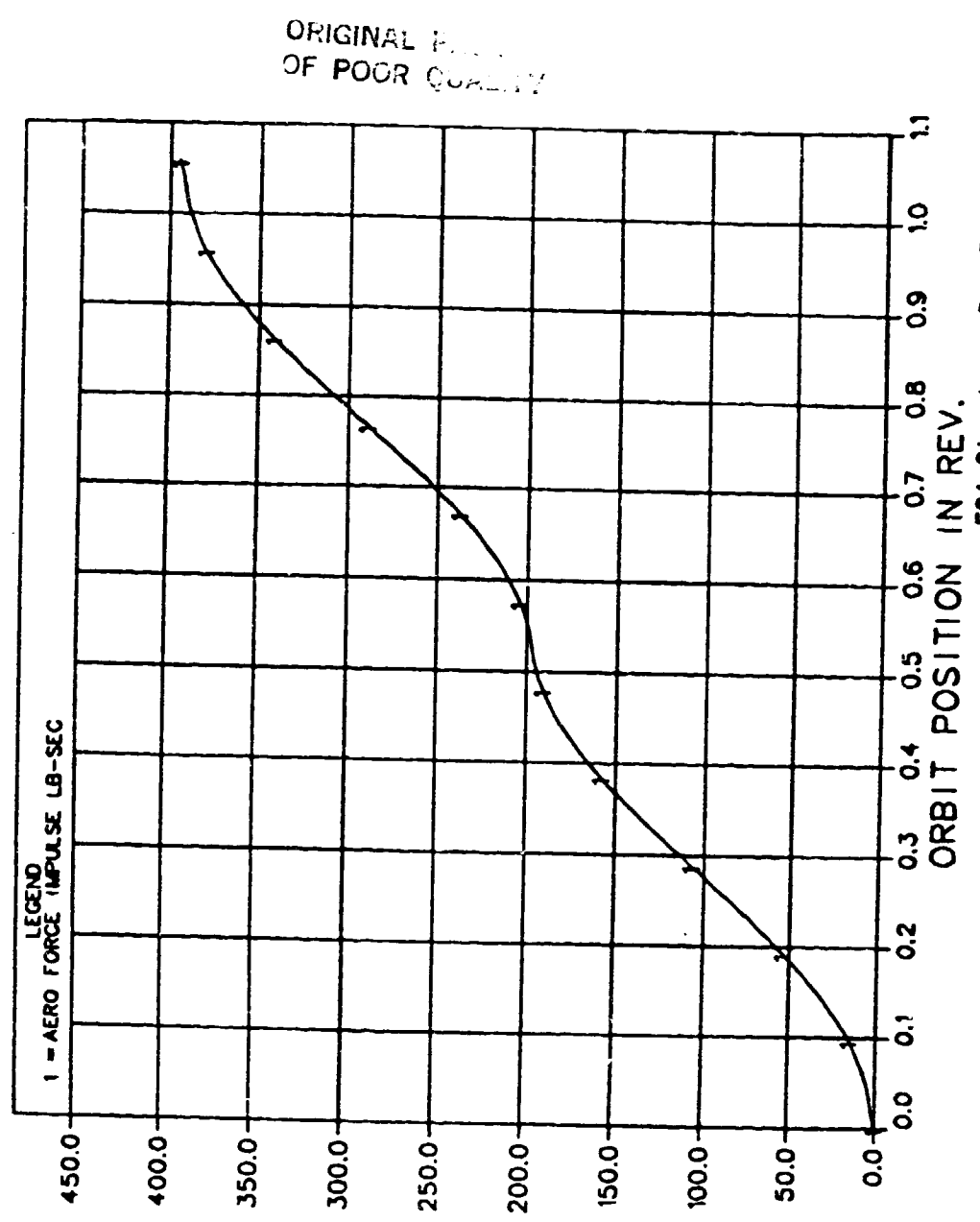
DEL GROW, INCL=0.0, SUN=-52, DELTA AT PRIN, SOLAR INERTIAL



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Figure 3.3.3.2-9 Delta-GROWTH Momentum Accumulation Time History

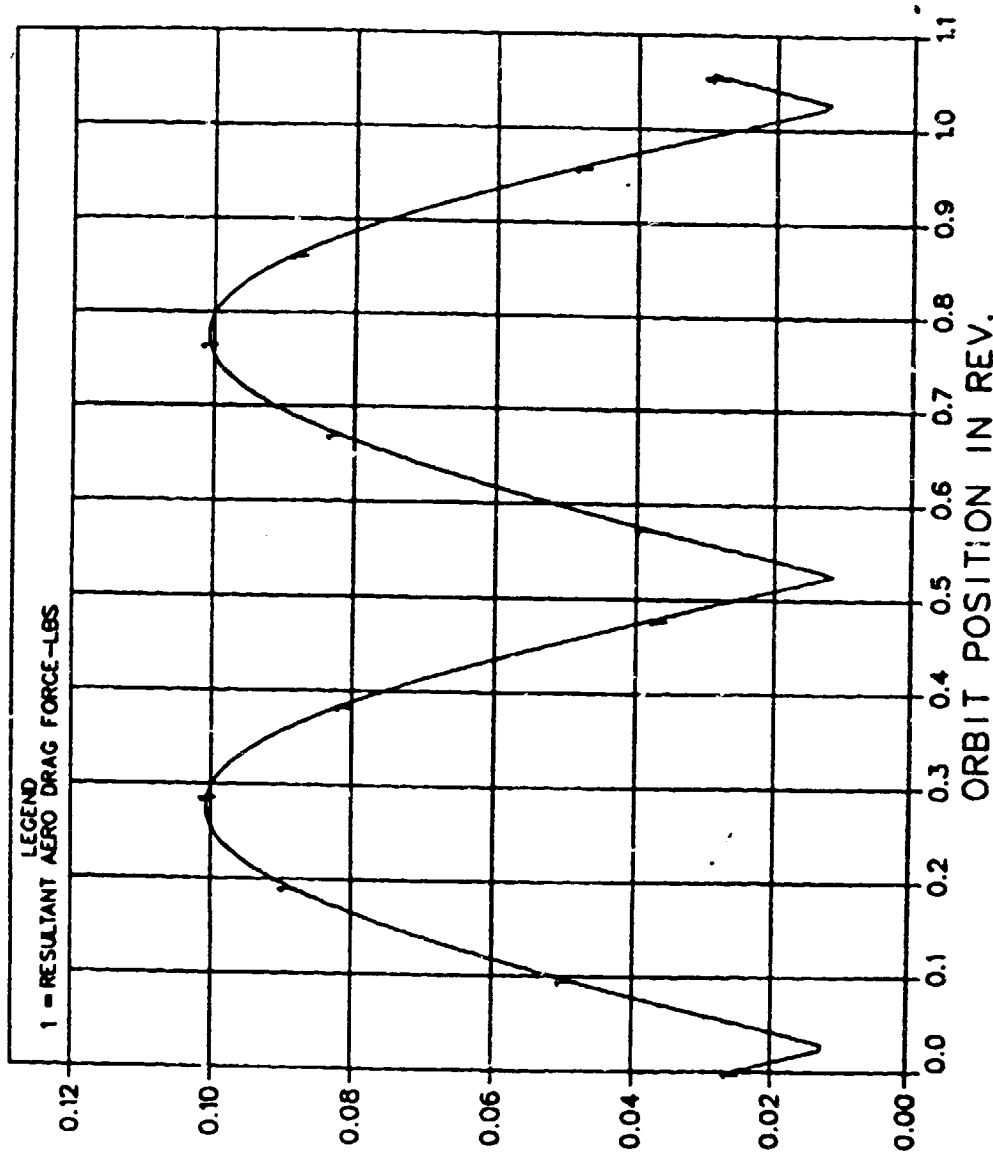
DEL GROW, INCL=0.0, SUN=-52, DELTA AT PRIN, SOLAR INERTIAL



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Figure 3.3.3.2-10 Delta-GROWTH Aerodynamic Drag Impulse Time History

DEL GROW, INCL=0.0, SUN=-52, DELTA AT PRIN, SOLAR INERTIAL

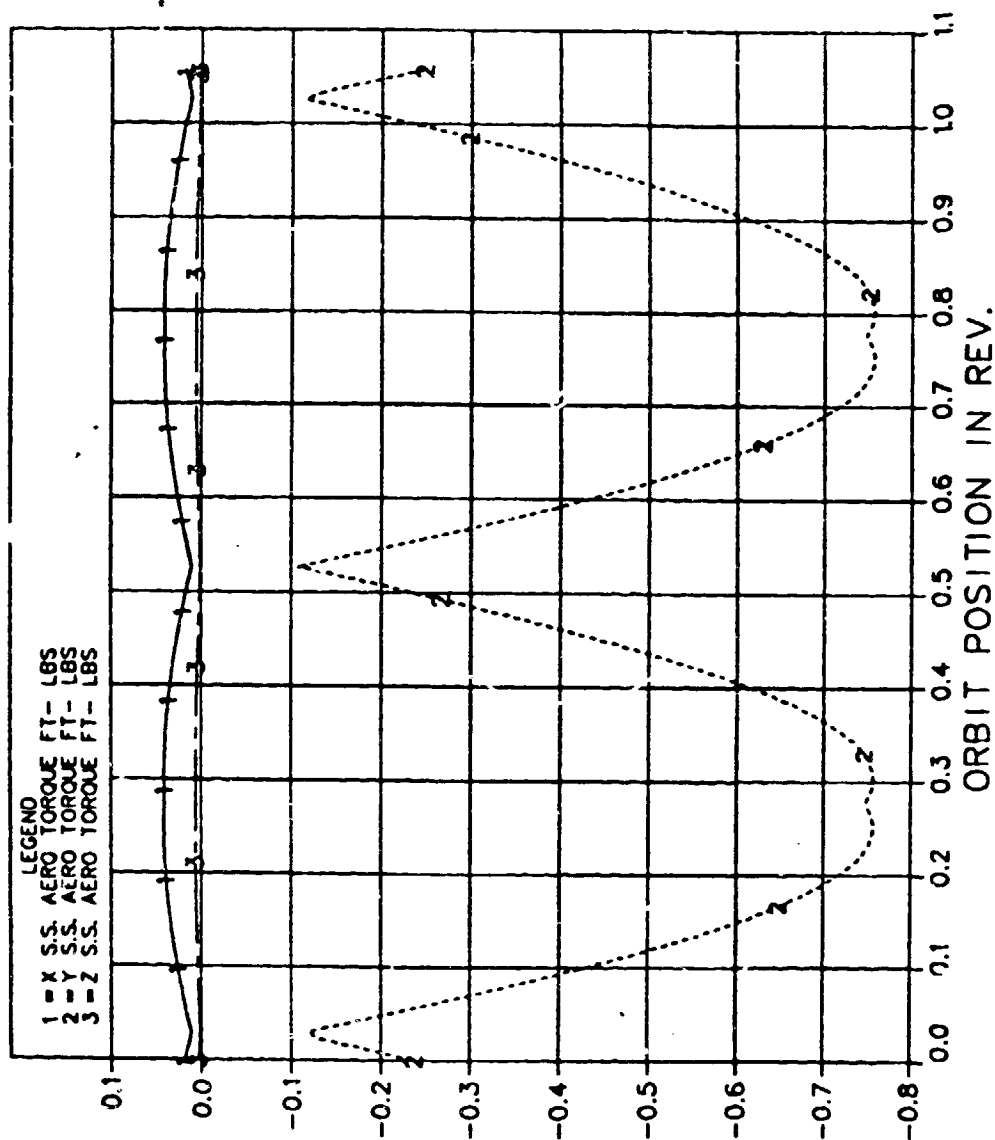


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Figure 3.3.3.2-11 Delta-GROWTH Total Aerodynamic Drag Force Time History

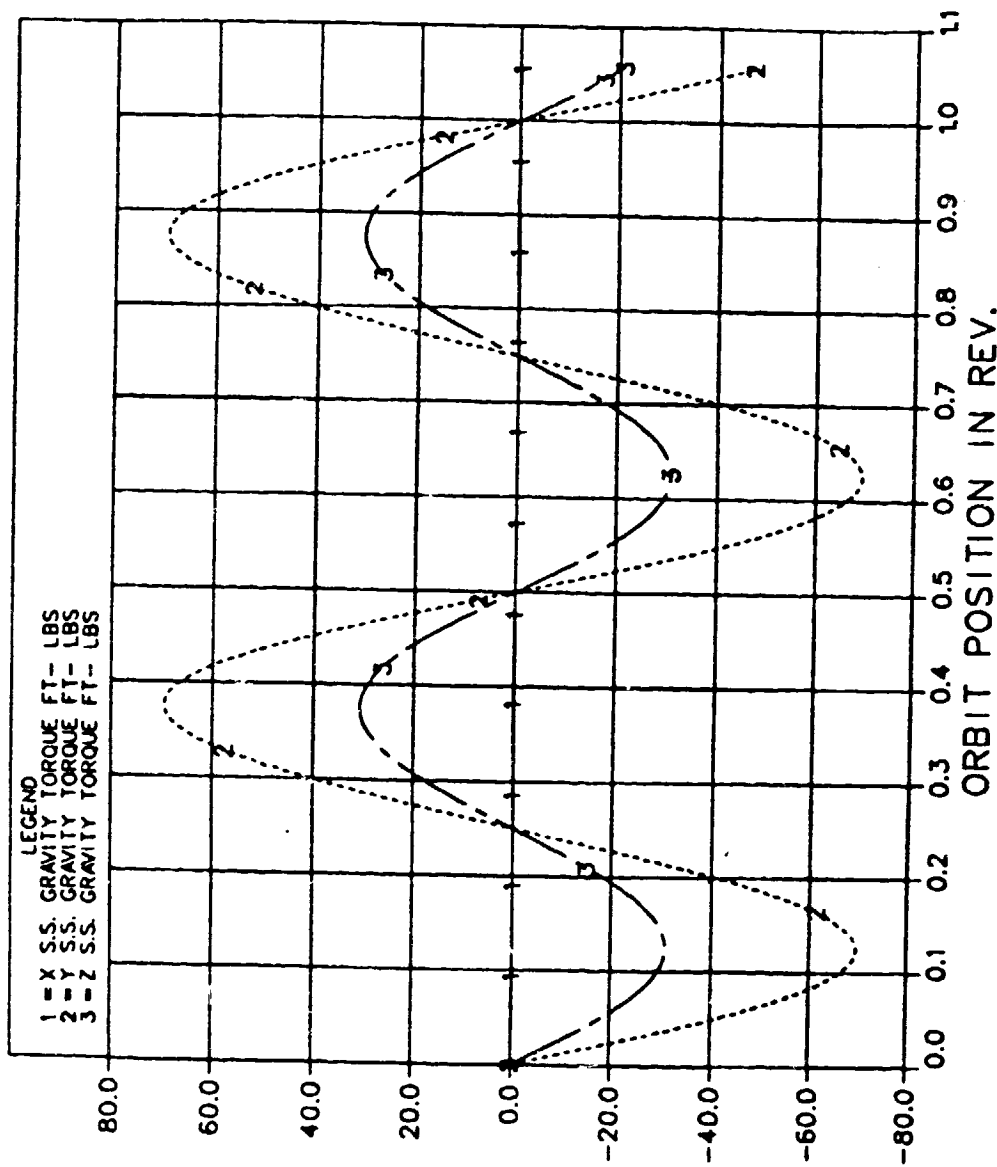
SOC-G, INCL=0.0, SUN=-52, ARRAY=0, ORB RATE YC AXES



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Figure 3.3.3.2-11a BBC-IOC Aerodynamic Torque Time History

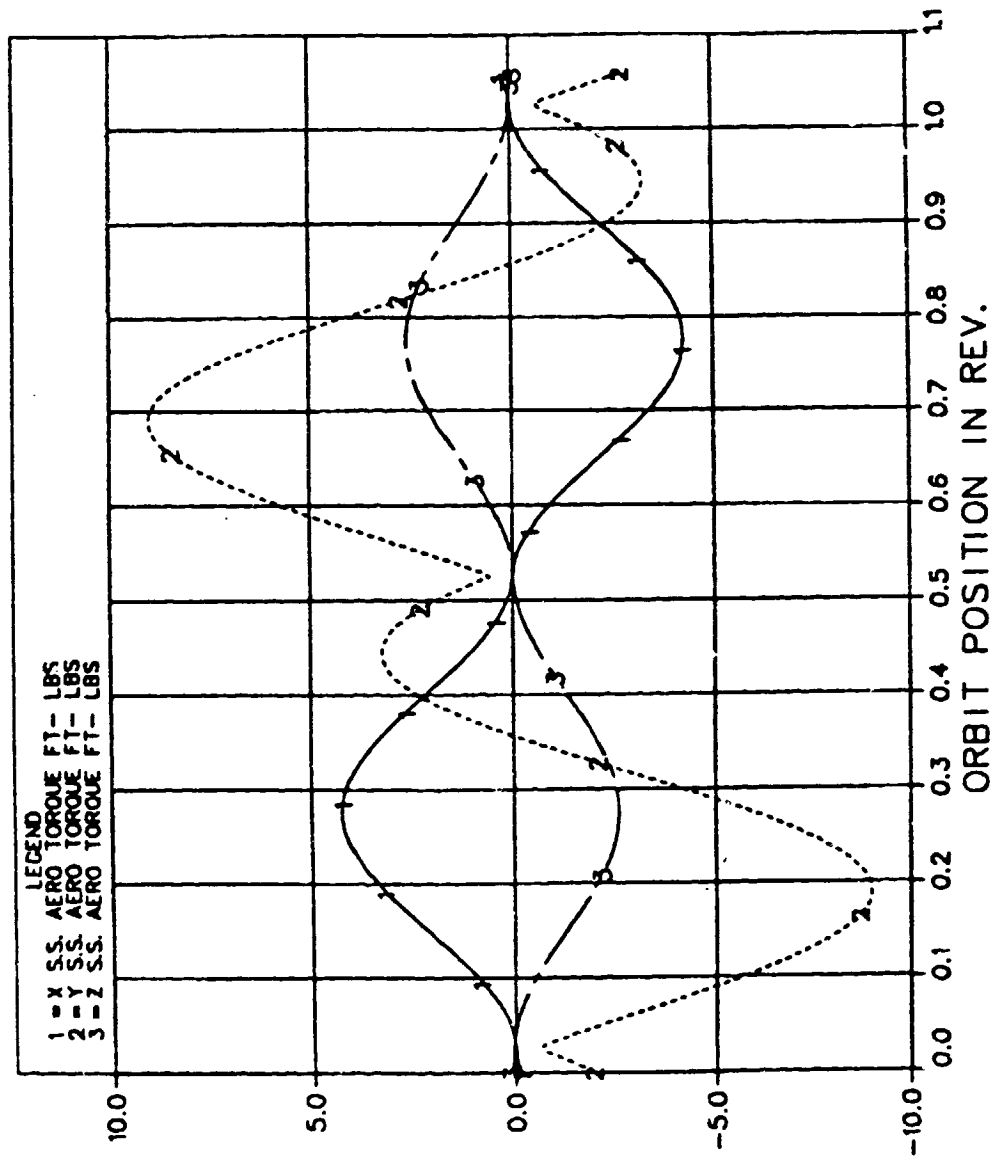
DEL GROW, INCL=0.0, SUN=-52, DELTA AT PRIN, SOLAR INERTIAL



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Figure 3.3.3.2-12 Delta-GROWTH Total Gravity Gradient Torque Time History

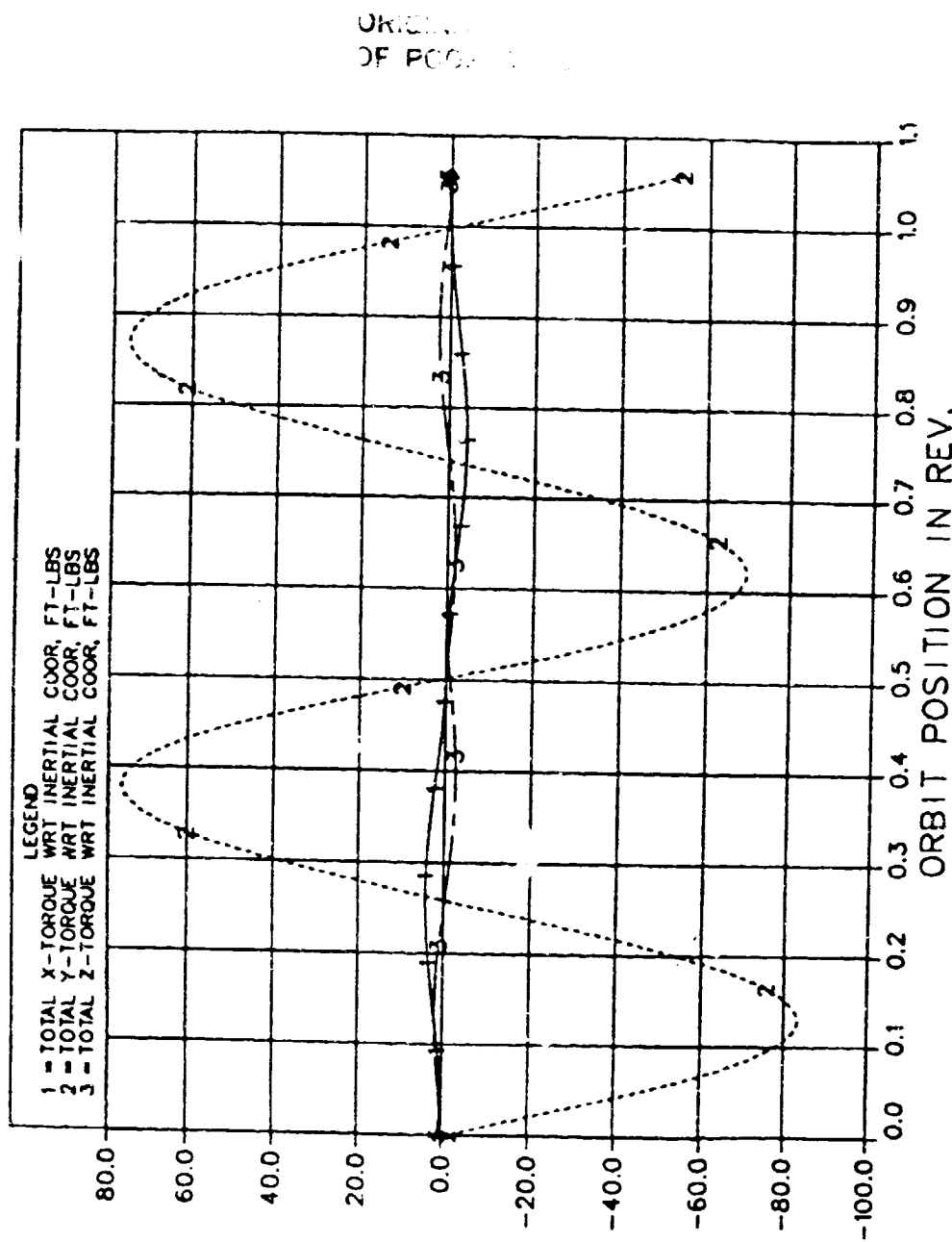
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Figure 3.3.3.2-13 Delta-GROWTH Aerodynamic Torque Time History

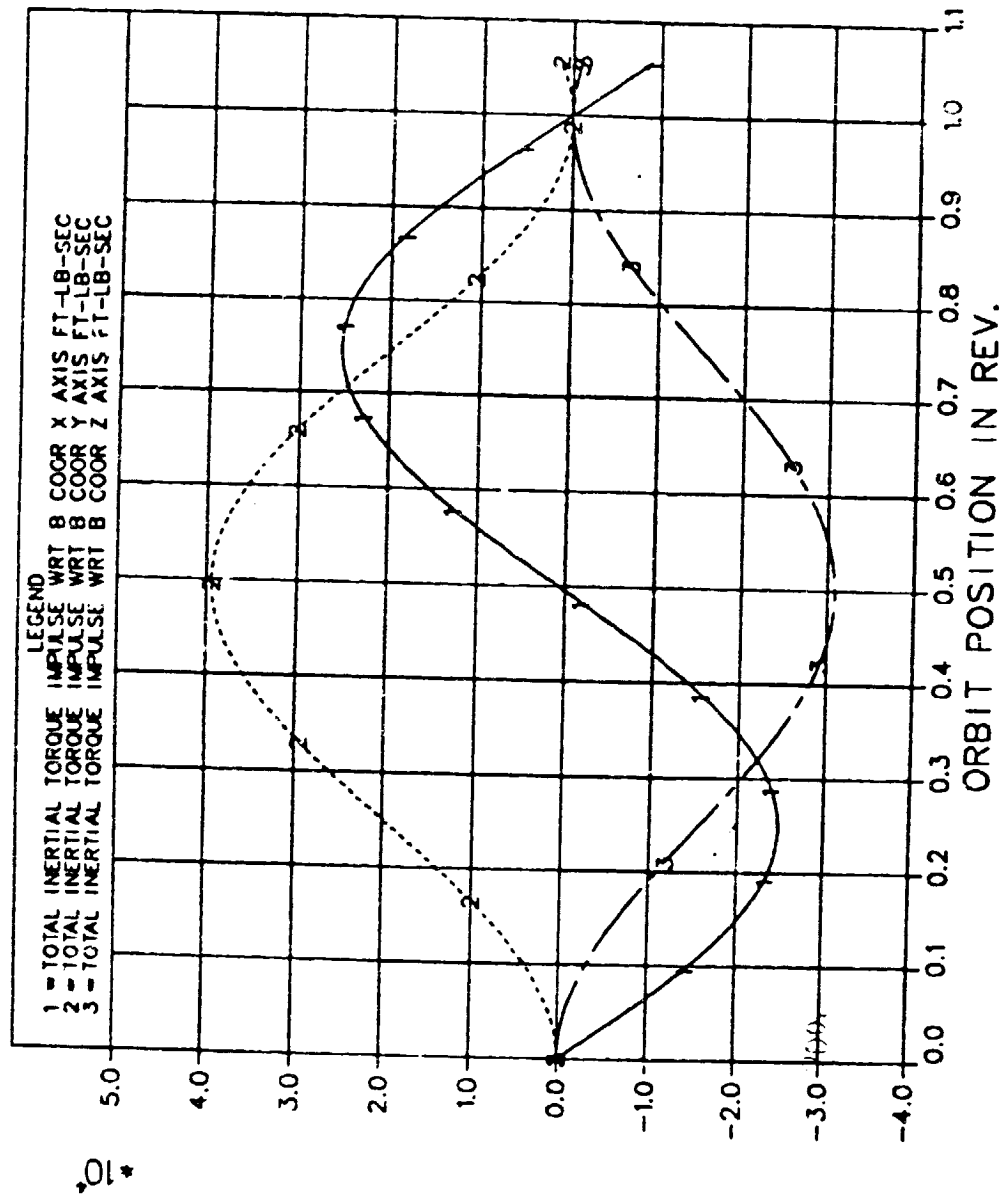
DELGROW, INCL=0.0, SUN=-52, DELTA AT PRIN, SOLAR INERTIAL



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Figure 3.3.3.2-14 Delta-GROWTH Total External Disturbance Torque Time History

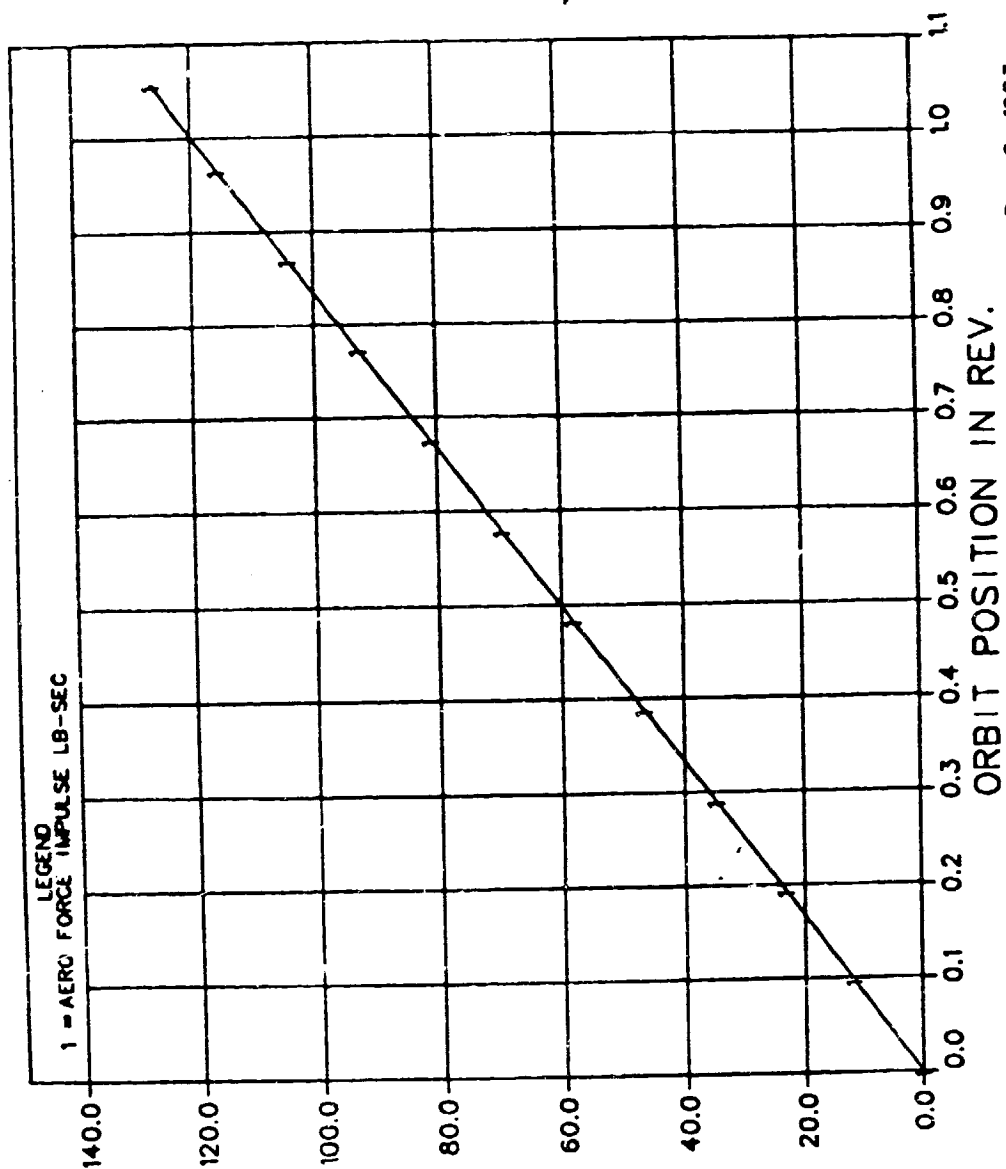
DELGROW, INCL=28.5, SUN=-22.5, DELTA AT 0, EARTH FIXED



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Figure 3.3.3.2-15 Delta-GROWTH Momentum Accumulation Time History

DELGROW, INCL=28.5, SUN=-22.5, DELTA AT 0, EARTH FIXED



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Figure 3.3.3.2-16 Delta-GROWTH Aerodynamic Drag Impulse Time History

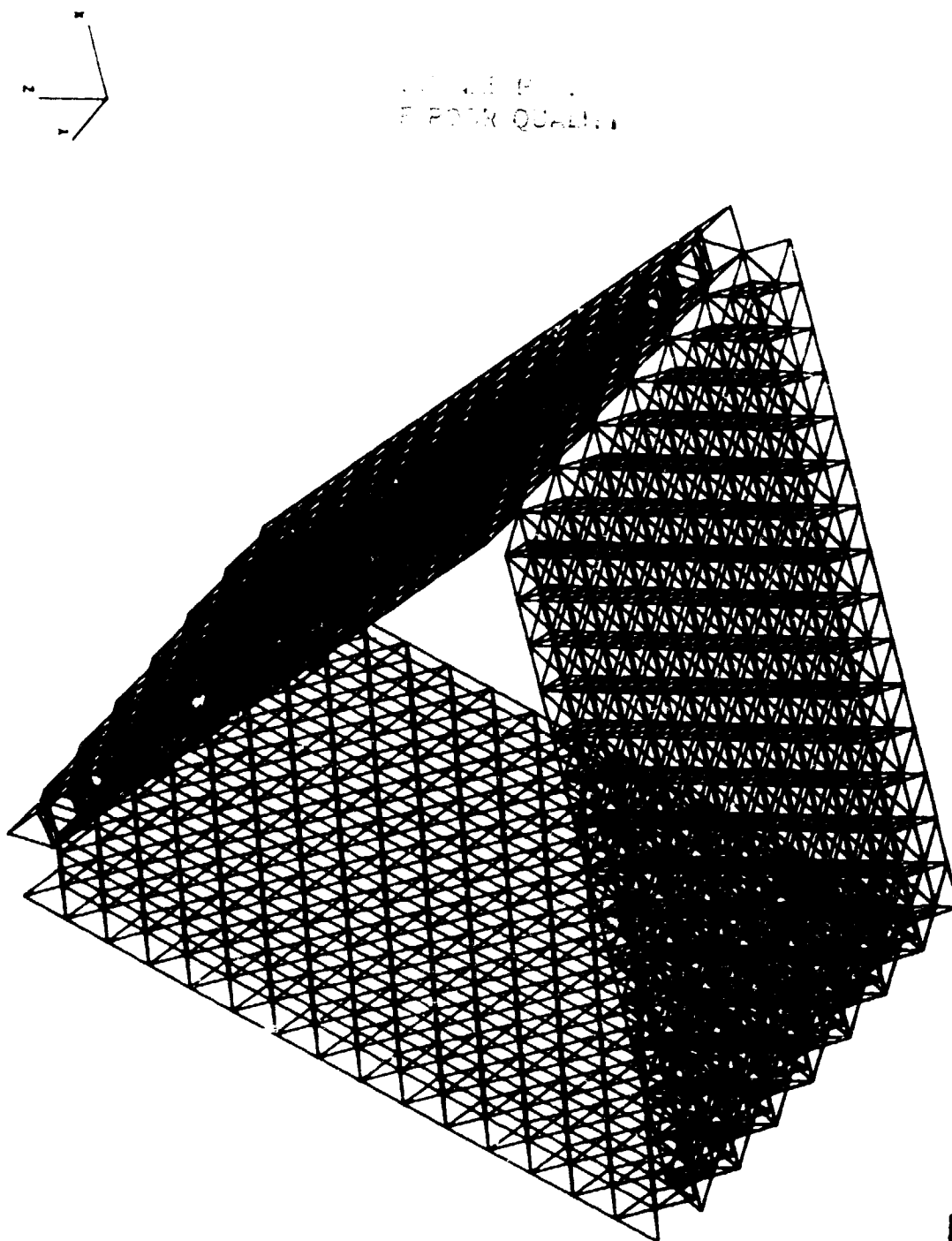
3.3.3.2-10 Results of the On-Orbit Flight Dynamics of the Delta Growth Farth Fixed Flight Mode (LVLH)

The TEA flight condition was achieved for the Delta by flying the Delta at different pitch attitudes and iterating to a resulting equilibrium condition. The results of the on-orbit flight dynamics are shown figures 3.3.3.2-15 through 3.3.3.2-16. The torque impulse curve shown in figure 3.3.3.2-15 shows no secular components at the end of an orbit. The cyclic momentum storage requirement is 25,000 ft-lb-sec. The aerodynamic drag impulse is shown in figure 3.3.3.2-16 and is 120 lbs-seconds per orbit. The gravity gradient torque vector with respect to the body axes is a constant equal to (20.5, -1.77, 2-ft-sec) ft-lbs. The aerodynamic torque vector with respect to the body axes is constant and equal to (-17, -1.48, .05) ft-lbs.

3.3.3.2.11 Structural Dynamics and Control

Finite element modeling was used to analyze the truss and module structure of the Delta Space Station concept (figure 3.3.3.2-17). The triangle configuration utilizes the stiffness benefits of the truss coupled with the inherent structural stability of the three bar link. The solar inertial pointing array guarantees that the natural frequency penalties caused by excessive array areas are minimized. These features result in a first mode frequency (array bending) of 4 Hz. The module placement allows for multiple attachment to the truss along the entire length of the module structure, increasing module flex frequencies.

A single axis rigid body controller was designed and analyzed for the Delta Space Station. Vehicle dynamics were modeled using the largest rotational inertia properties. A second order model for the CDG's and angular rate was assumed. The resulting closed loop system has nearly critically damped CMG/rate poles near the open loop values. Frequency analysis was accomplished



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STRUCTURAL ANALYSIS BRANCH
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GAMMA : 0.0 000.

Figure 3.3.3.2-17 Finite Element Model of the Triangle Space Station

using the Bode plot. The Delta exhibited time response faster than the Streamlined "T", but slower than the BB Configuration. The time performance is directly accountable to the rotational inertia employed in the vehicle dynamics model. The frequency response indicates controller authority to 0.4 Hz. The flex analysis shows the first flex mode at 4 Hz giving this system an order of magnitude separation between controller passband and structural dynamics. These results indicate that simple rigid body control system designs may suffice for the Delta configuration.

The structural dynamics of the Delta Space Station during intermediate buildup stages was not analyzed at this time. The triangle, with its single launch truss system, is a dynamically stable configuration during the construction phase. Similar to the "T" concept, once the truss is in place, the addition of modules will not degrade the system dynamic response.

The results of this study indicate the advantages of truss systems as the primary structure of Space Stations. The trusses allow a stable platform of large dimension while retaining adequate dynamic characteristics. The triangle demonstrated the highest natural frequency and structural stability of the three configurations studied.

The relative flexibilities of various station concepts are analyzed because of its known impact on system maneuvering performance and attitude control capability. These are not the only flexibility concerns on the station system. Experiments that require pointing accuracy will require isolation systems that are impacted by system flexibility; the more flexible the platform (Space Station), the more demanding the requirements of the isolation. In addition, for experiments in large flexible space structures (antennas, etc.), the more flexible the test platform, the more complicated the experiment since test article math models must include high order models of

the platform.

3.3.3.2-12 Summary of On-Orbit Flight Dynamics

The flight dynamics of the three proposed Delta configurations have been studied in detail for two flight modes:

1. Solar inertial attitude hold
2. Earth fixed (LVLH) attitude hold

Using mass properties management to control the system inertias and TEA trim adjustment, the momentum accumulation can be reduced to zero for both flight modes. Propellant resupply weight of up to 2,400 lbs. for orbit maintenance does not seem to be a critical item.

From the structural dynamics standpoint, the triangle concept is clearly the most dynamically efficient Space Station candidate. The triangle possesses a substantial stiffness (cruss) and minimal array size and weight.

3.3.3.3 Communications Evaluation

The communication subsystem consists of hardware required to establish communication links between the Space Station and various vehicles. Antenna requirements for the subsystem are essentially the sum total of those requirements developed by considering each link separately. In this subsection, we will develop antenna specifications for the delta truss configuration by sequentially describing each operating link. Information on RF coverage, number of required antennas, type, makeup and size of these antennas, and their estimated locations on the Space Station structure are given. Also, the ease of procurement or development of such antennas is discussed.

The delta truss configuration rotates to keep one face always pointing toward the sun. In its local coordinate system, the coverage associated with each

link is for all practical purposes, a full sphere. This wide coverage is in contrast to the limited one that usually results in the configurations which are gravity gradient stabilized. Hence, the number of antennas required to serve a given link in the delta truss would be larger than that required to serve the same link in the other two configurations because we simply have a lot more space to cover. However, to reduce the number of antennas on the Delta truss, it may be possible to use the more complex conformal arrays with spherical geometry which may also require special mounting techniques depending on their location on the Space Station. Alternatively, if a stabilized platform is provided with the delta truss, be used for the mounting of antennas, then the number of antennas may be reduced.

In the following discussion of individual links operating with the delta truss, the coverage is assumed spherical on every link and thus, antennas are specified accordingly. The antenna design selected for this configuration to meet each required link coverage was based on studies that have been completed to date. Further study and evaluation could dictate alternative options that might be more advantageous based on numbers of antennas required and development risks.

A summary of the antenna requirements for the Delta truss is given in Table 3.3.3.3-1. The antenna locations for the IOC and growth Delta truss configuration is shown in figures 2.3-1 and 2.3-2.

a. Space Shuttle Orbiter (SSO) link - This is a S-band link that supports two-way communication between the Space Station and the Space Shuttle Orbiter. Only one SSO is supported in IOC and two SSO's are supported in the growth version.

Table 3.3.3.3-1

Antenna Requirements for the Delta Truss Configuration

<u>Communication Link</u>	<u>Antenna Type</u>	<u>Number of Antennas</u>	
		<u>IOC</u>	<u>Growth</u>
Space Shuttle Orbiter	S-band medium gain phased array	3	3
Multiple access link to EMU, FF, OMV vehicles	K-band high gain multibeam phased array	3	3
Tracking and Data Relay Satellite	S/Ku-band dual feed dual frequency steerable parabolic reflector	3	3
Global Positioning System	L-band widebeam omni	3	3
Television	K-band high gain single beam phased array	6	18
Orbital Transfer vehicle	k-band medium gain multibeam phased array	0	3
Space Shuttle Orbiter Rendezvous Radar	Omni directional	2	2
Rendezvous	Parabolic Reflector monopulse feed	3	3
Multiple Tracking	High gain phased array	0	5

The link is to be served by three medium gain (30 dB) phased array antennas. Each array is made up of about 500 elements and measures about 10 feet in diameter. Two antennas are located on the vertex lines running from the front triangle to the back triangle. A third antenna is located on the underside of the habitat module.

The procurement of these antennas represent routine design and development effort if the arrays are passive (electronics separate from antenna elements). However, some risk is introduced in the development if the arrays are active with monolithic design (electronics combined with the antenna elements in one package).

b. Multiple access (MA) link - This is a K-band link that support two-way communication between the Space Station and the EMU, FF, and OMV vehicles.

Three high gain (41 dB) multibeam phased array antennas made up of about 16,000 elements and measuring about 28 inches in diameter each will provide the required spherical coverage. They are located on the Space Station as follows. Two antennas are positioned along the vertex lines running from front triangle to the back triangle next to the solar array. A third antenna is located on the underside of the command/control module.

The above specification for the three high gain antennas assumed an operating frequency in the K-band at about 28 GHz. There will be medium amount of risk associated with the development of such a large array antenna (16,000 elements) in the passive mode. The risk becomes high if the array design is active and monolithic. The design difficulty can be reduced considerably by moving to a lower frequency like Ku-band where an array size of about 1,000 elements will be sufficient due to lower antenna gain (30 dB) and higher antenna efficiency.

c. Tracking and Data Relay Satellite (TDRS) link - This is a dual S/Ku-band link that supports two-way communication between the Space Station and the TDRS satellite.

The link to be served with three dual-feed, dual-frequency mechanically steerable parabolic reflectors of nine feet diameter. Two dishes are located along the vertex lines connecting front and back triangles and adjacent to the solar array. The third dish is located on the underside of the habitat module #1.

Procurement of the parabolic reflector antennas required on this link is subject to a medium level of risk arising from the adaptation of the two feed systems to the mechanically steerable parabolic reflector.

d. TV links to FF's and OMV's - These are independent Ku-band links relaying digital TV signals from the FF's and OMV's back to the Space Station. Two links are needed in the IOC stage (6 antennas) increasing to six links in the growth stage (18 antennas). The coverage on each link will be a 20° cone out to 2,000 km for far range coverage and a hemisphere below the station extending 50 km.

Each link can best be served by high gain conformal phased arrays to obtain a spherical coverage with minimum number of antennas. Each array will have a diameter of about four feet. The antennas for the first three TV links are spaced along the sides of the front triangle; those for the last three TV links are spaced along the sides of the back triangle.

The antenna arrays for these TV links represent high risk development items due to the large number of elements that would be involved in the design.

e. Orbital Transfer Vehicle (OTV) link - This is a K-band link supporting two-way communication with the OTV in the growth configuration

only. The coverage is a full sphere with a maximum radius of 100 km.

The link can be served by a group of three medium gain phased array antennas each covering one-third of the sphere. The size of each array is 400 elements at Ka-band frequency and measures about five inches in diameter. The placement of these antennas on the Space Station is as follows: two antennas are located along the vertex lines connecting front and back triangles on either side of the solar array. The third antenna is located on the underside of the lab module (the one adjacent to the habitat module).

The development of the three array antennas presents no risk if the array is passive. Minimum risk results if the array is active.

f. Tracking Links

Four links will be used to provide Space Station position and attitude information, and to provide relative position and velocity information on other Space Colony vehicles and objects within specified volumes of concern. The Global Positioning System (GPS) Satellite Constellation Link is an L-band receive-only navigation and tracking link. The Space Station GPS antenna must be able to receive code tracking information from a group of four satellites simultaneously. The antenna coverage consists of a 160° cone centered about the Space Station local vertical.

The link would be satisfactorily served by a low gain omnidirectional antenna. This antenna must be mounted on the Space Station in such a way that most of the upper hemisphere is clearly visible. On this configuration, it is mounted on the left solar panel boom.

Procurement of such an antenna is routine, and there is no development risk involved.

A Shuttle Rendezvous Radar link will be completed by a transponder onboard the Space Station. Two transponders and two omnidirectional antennas will be used for this link.

Rendezvous radar links will be used to maintain continuous position and velocity data on vehicles that are approaching the Space Station during the implementation of flight plans which involve docking. Similar position and velocity data will be provided for vehicles that are departing, and are within a specified range of concern. Two antennas, directed fore and aft along the velocity vector, will be used for this function; each antenna is expected to be approximately three feet in diameter.

Multiple vehicle tracking will be accomplished by Search and Track Radars which will maintain updated position information on vehicles at distances as great as 2,000 km. A minimum of five antennas will be used for this purpose, to provide coverage of the fore and aft directions along the velocity vector. A maximum of four antennas will be used to provide complete coverage of a specified volume around the Space Station.

3.3.3.4 Elements/Utilities Interfaces and Mechanisms Evaluation

3.3.3.4.1 General

The central structural element of the delta truss configuration is the open triangular structure formed by joining three flat tetratruss platforms. The modules, solar arrays, radiators, servicing facilities, utilities and other elements are attached to the truss structure. The modules are joined using the structural and mechanical elements of the berthing interface mechanism as described for the building block configuration, but the proximity of the truss structure to the modules offers options on routing of utilities.

Much of the mechanical systems and interface study effort has focused on

assembly of major station elements and on concepts for utilities wiring and plumbing. A major objective is to develop concepts which are compatible with manipulator operations and minimize EVA requirements. In some cases, more detailed design activity will be required to fully establish practical levels of manipulator versus EVA operations. For example, concepts for placement of station electrical wiring using the manipulator appear practical, but limited use of EVA for mating of connectors may avert the need for development of sophisticated mechanisms for that limited purpose. There is a need for more specific trade studies of EVA versus manipulator activities as well as continued evaluation of manipulator capability and complexity of manipulator operations versus capability of assembly mechanisms.

3.3.3.4.2 Berthing Mechanism

Berthing involves use of a manipulator to achieve final closure of two spacecraft or assembly elements, thereby insuring relatively small misalignments and contact velocities. Contact energy attenuation requirements are low and alignment guides are shorter than would be required for docking operations. The berthing interface comprises alignment guides, structural latches, a telescoping pressure tunnel, retract/extend actuators, utilities interconnect provisions and supporting structure. See figure 3.3.3.4-1. Note that the delta configuration incorporates three guides to provide 120° indexing for station elements. Guide length of 5.75" will accommodate expected misalignments for berthing operations. The manipulator, aided by the alignment guides and other sensors as required, brings the interfaces within the envelope of the combined capture/structural latches. Operation of these six latches, located on the alignment guides, completes the structural mating of the interface. The structural latches are sized to carry the full pressure load and all dynamically induced loads across the interface. Within the 15"

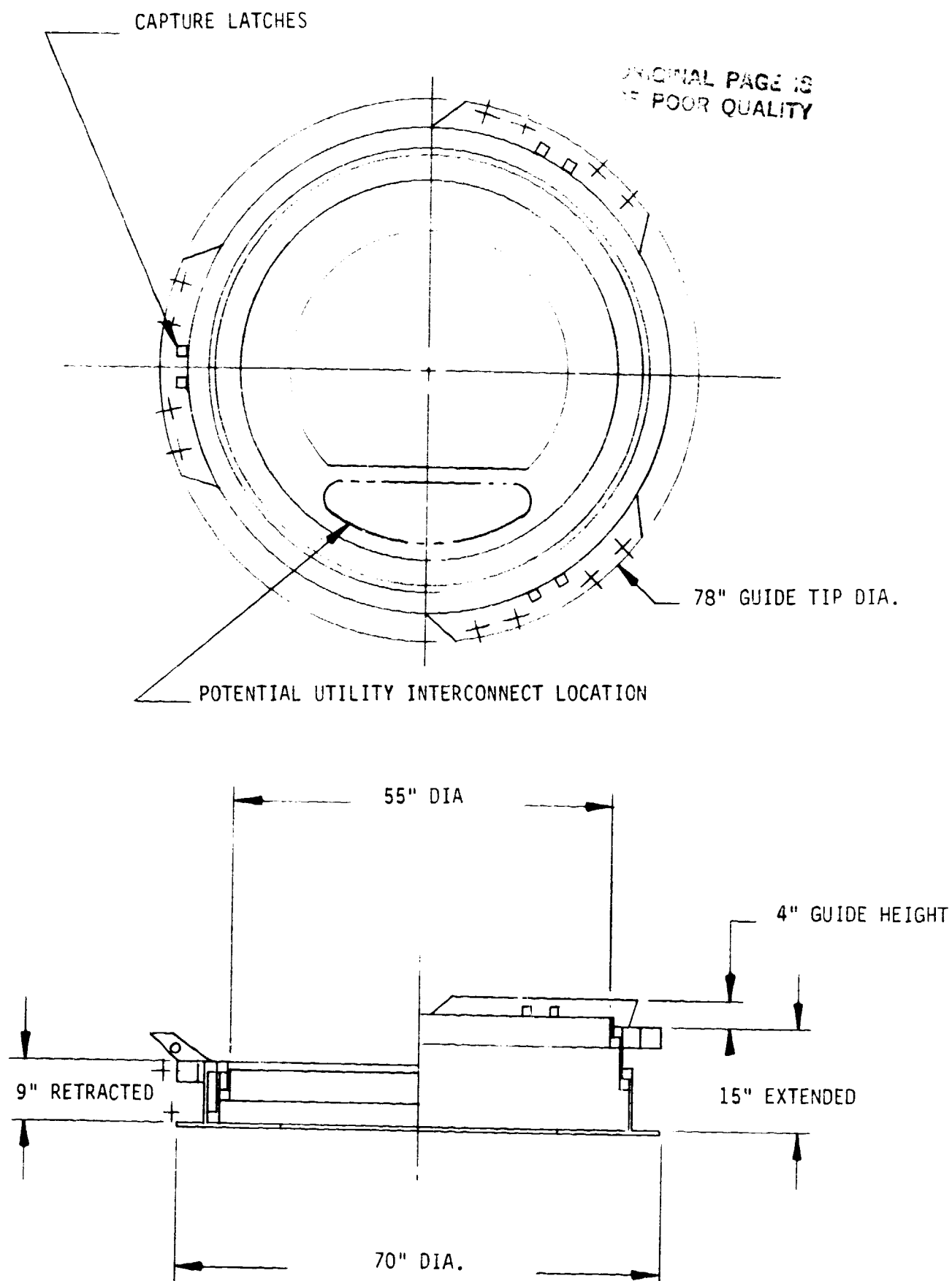


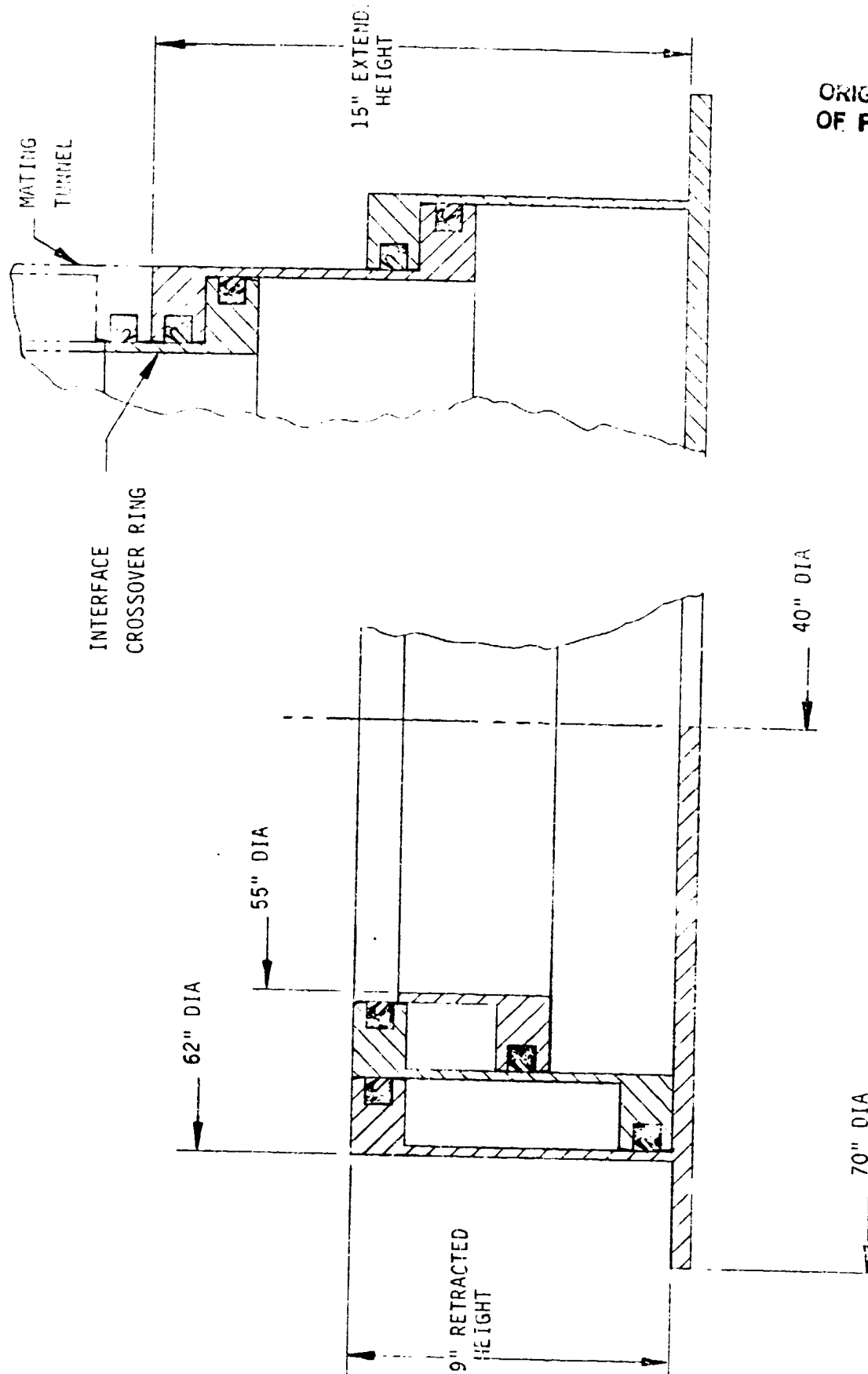
FIGURE 3.3.3.4-1 THREE GUIDE BERTHING INTERFACE

length of the berthing mechanism, a 6" stroke of the mating interface will be provided by three pairs of electromechanical actuators. After structural mating is accomplished, these actuators will be fully extended.

The telescoping pressure tunnel, shown in figure 3.3.3.4-2, is extended by independent small electromechanical actuators. The tunnel concept incorporates redundant pressure seals and a complete set of tunnel elements may be extended from either side of the interface.

Truss mounting of the modules may greatly modify the requirements for the berthing interface. If modules can be berthed first to the truss attachment structure, the module to module interface can be simplified. Further, the truss attachment may reduce the loads across the berthing interface, thereby reducing structural requirements. These effects could not be evaluated in sufficient depth to warrant changing the baseline berthing mechanism at this time.

The size and type of utilities interconnects which must cross the berthing interface are shown in table 3.3.3.4-1. Utilities may be routed through the berthing interface in the same manner as for the building block configurations. Alternately, the close proximity of the truss structure provides the option of installing some utilities busses on the truss structure, with independent parallel connections to the modules. This is a natural choice for thermal control since the freon fluid and vapor busses must be located outside the modules and the system is necessarily plumbed with this parallel structure. The advantage of truss mounting the main supply busses is that a module may be removed without interrupting service to the remaining modules. Concepts for truss mounting of the electrical power and thermal transport busses are described in the following section.



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FIGURE 3.3.3.4-2 TELESCOPING TUNNEL

NAME	NO.	TYPE	COMMODITY	QUANTITY	UNITS	SIZE	MATERIAL
FREON SUPPLY	1	H. PRESS. LIQ.	FREON	2500	LB/HR	1" ID. TUBE	S. STEEL
FREON RETURN	1	L. PRESS. BI-PH.	FREON	2500	LB/HR	2" ID. TUBE	S. STEEL
COOLANT SUPPLY	1	L. PRESS. LIQ.	WATER	500	LB/HR	3/4" ID. TUBE	S. STEEL
COOLANT RETURN	1	L. PRESS. LIQ.	WATER	500	LB/HR	3/4" ID. TUBE	S. STEEL
DRINKING WATER	1	L. PRESS LIQ.	WATER	50	LB/DAY	.5" ID. TUBE	S. STEEL
WASTE WATER	1	L. PRESS. LIQ.	URINE/FLUSH	100	LB/DAY	.5" ID. TUBE	S. STEEL
OXYGEN SUPPLY	1	MED. PRESS. GAS	OXYGEN	20	LB/DAY	3/8" ID. TUBE	S. STEEL
NITROGEN SUPPLY	1	MED. PRESS. GAS	NITROGEN	5	LB/DAY	1/4" ID. TUBE	S. STEEL
WASTE WATER	1	L. PRESS. LIQ.	CONDENSATE	3	LB/HR	1/2" ID. TUBE	S. STEEL
WASH WATER	1	MED. PRESS. LIQ.	GRAY WATER	150	LB/DAY	1/2" ID. TUBE	S. STEEL
AIR SUPPLY	1	LOW PRESS. GAS	AIR	150	CFM	4" ID. TUBE	S. STEEL
DATA ACQ/TLM	4	MULT. COND. CABLE	DIGITAL DATA	--	--	40 WIRE CONN.	COMPOSITE
T,C&N CNTRL/STATUS	4	MULT. COND. CABLE	DIGITAL DATA	--	--	8 WIRE CONN.	---
AUDIO CONTROL	2	FIBER OPTIC	DIGITAL DATA	--	--	1/2" DIA. CONN.	---
AUDIO SIGNAL	2	FIBER OPTIC	DIGITAL DATA	--	--	1/2" DIA. CONN.	---
REGIONAL DATA BUS	4	FIBER OPTIC	DIGITAL DATA	--	--	1/2" DIA. CONN.	---
POWER. DIST. CNTRL BUS	4	FIBER OPTIC	DIGITAL DATA	--	--	1/2" DIA. CONN.	---
POWER SUPPLY	4	INDUCTIVE	HIGH VOLT. AC	25	KW	6" DIA. CONEPAIR	---
MISC. DATA BUS	8	FIBER OPTIC	DIGITAL DATA	--	--	1/2" DIA. CONN.	---

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TABLE 3.3.3.4-1 INTERMODULE UTILITIES INTERFACES

3.3.3.4.3 Truss Mounted Utilities Interfaces

The solar arrays and Power Conditioning Modules (PCM) are installed on the upper truss surface. Figure 3.3.3.4-3 illustrates a concept for power distribution to the various modules. DC power is delivered from the solar arrays to the PCM's with two pairs of #4 wire with two connectors at each end as shown. At this point, the power is converted into three phase 400 VAC and four distribution busses are routed from each PCM down near the base of the truss structure where the modules are located. These 4 busses are connected to a main distribution four bus system which is attached to and encircles the truss structure. Each module is then connected to these main distribution busses. Each module will contain four distribution busses for redundancy. Only two busses will be activated as supply busses at a given time. All connections within the AC power distribution circuit will be made with contactless (inductive) connectors. Installation of the power distribution system need not involve stringing wire. Prior JSC study efforts proposed use of cable trays which could be attached to the truss elements with simple push-on clamps. Cable runs longer than the Orbiter PLB could be accommodated with folding cable tray assemblies. Many details remain to be worked, but placement of the power distribution system using the manipulator does not appear impractical. EVA may be more attractive for connecting the various elements.

Details of the thermal transport concept are less well developed. Freon fluid and vapor busses must be connected from the truss mounted radiators to the various modules. Schematically, the concept is the same as for power distribution. Fluid and vapor lines will be routed from the radiators to main busses which are attached to and encircle the truss structure near the location of the modules. Each module will be independently connected to the

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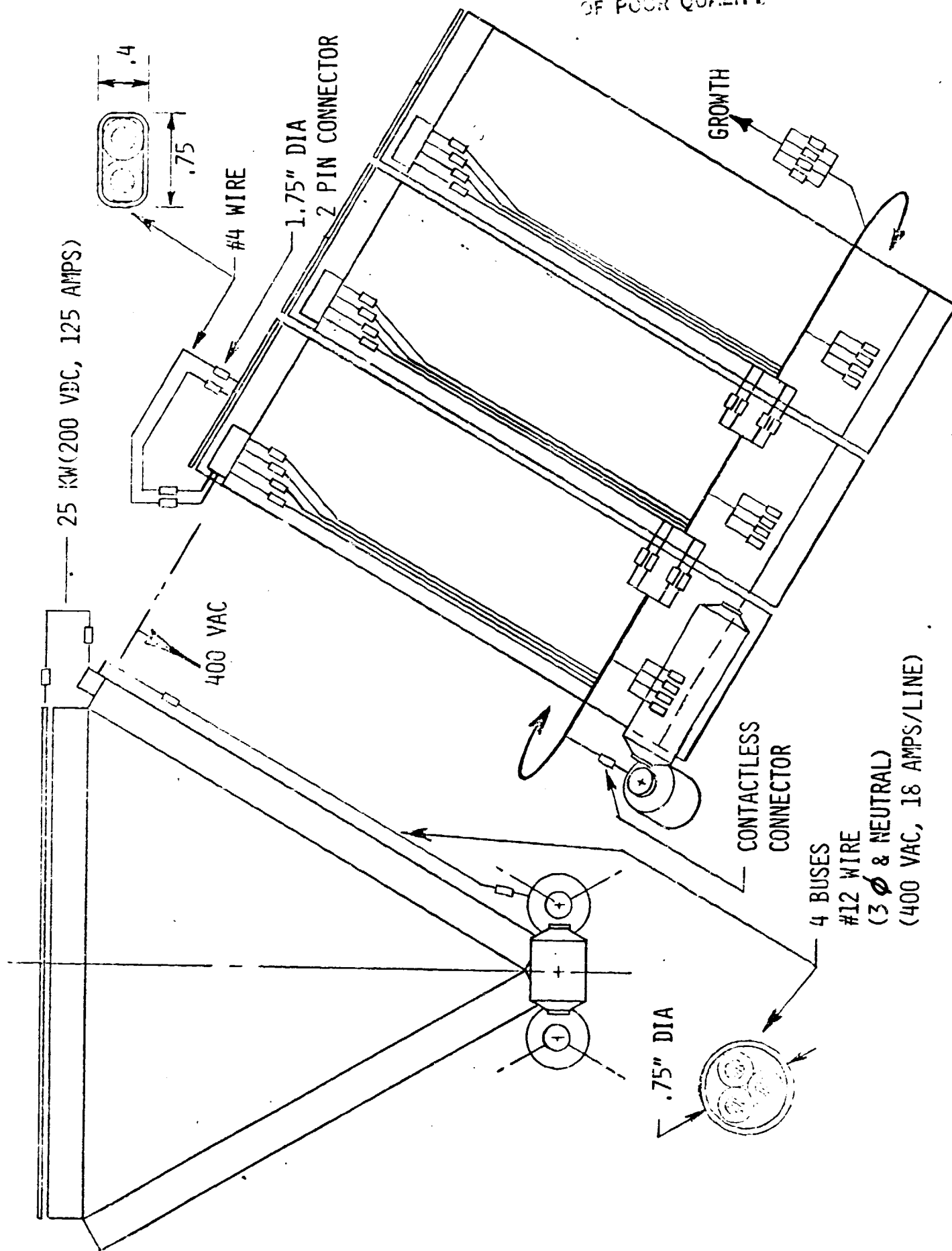


Figure 3.3.3.4-3. Power Distribution Concept-Delta Configuration

main busses, therefore, removal of a module will not interrupt service to the other modules. A typical module connection arrangement is shown in figure 3.3.3.4-4. Precharged line segments will be mounted to the truss structure and connected to form the thermal transport system. Use of tubing trays which easily attach to the truss structure may simplify the placement process but many connections must be made and verified. Significant EVA, or manipulator assisted EVA, may be required.

3.3.3.4.4 Element-to-Truss Attachment

Large elements must be attached to the truss structure at the nodes, where significant loads can be tolerated. The nodes will be designed to accept quick operating push in (pip pin) connectors and more sophisticated connectors capable of withstanding higher tensile loading. For low mass items such as cable trays, simple push on clamps which attach directly to the truss elements (approximately two-inch diameter tubing) may be adequate.

Each special truss attachment requirement must be worked in detail. Prior JSC studies identified several practical attachment concepts, including multiple tripod arrangements for attaching modules (or the OTV). For this study, a tripod module attachment scheme was evaluated for the purpose of weight estimation. Four tripods are employed, with each of the 12 legs attached to a truss node. Four lightweight retention fittings, which interface with the standard trunnions used to mount the module in the PLB, are attached to the upper ends of the tripods. Estimated weight for this concept is 0.5% of the attached module weight, so an attachment weight penalty of 0.5% of the weight of all elements attached to the truss was assessed.

The number of nodes available for attachment is quite limited, so detailed design of attachment concepts will be an important process, and one which may influence slight modifications in station element placement.

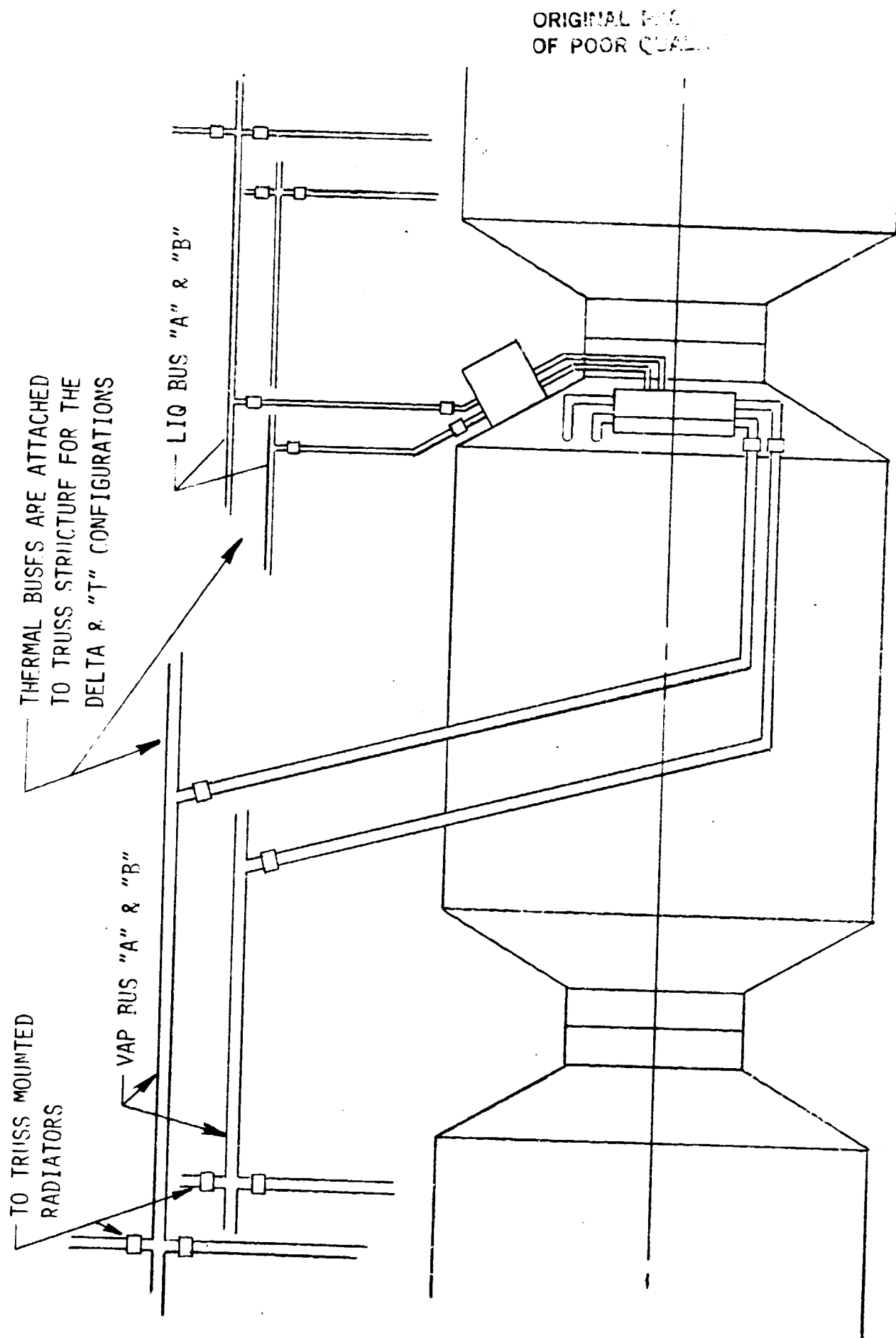


Figure 3.3.3.4-4. Thermal Connections Schematic Typical Arrangement for Delta & "T" Configuration

Certain nodes are exposed in the packaged condition of the truss. These nodes are ideal for attachment, prior to deployment, of one or more manipulator grapple fixtures to facilitate assembly.

3.3.3.4.5 Manipulator Systems

The Space Station manipulator will be the standard Orbiter RMS unless further detailed evaluation of the assembly process establishes the need for greater reach capability. The RMS shoulder will be mounted to a berthing interface mechanism modified to accommodate RMS power and control utilities only. Through the berthing interface, the manipulator may be stationed at any available berthing port. A special manipulator berthing port will be mounted to the side truss structure in optimum position to support station assembly and to service the OMV hangar. The growth configuration includes two additional manipulators identical to the first. A second special manipulator berthing port will be added at the opposite end of the side truss structure in position to service added hangar elements. The third manipulator will be stationed at a lower berthing port for use in the satellite servicing area.

3.3.3.4.6 Hangar and Satellite Servicing Mechanisms

The OMV and OTV hangars will be constructed inside the triangular truss structure. The satellite servicing area, located beneath the modules, comprises beams attached to the truss structure. The beams, representative of the Orbiter PLB longerons and keel, will incorporate lightweight Orbiter payload retention fittings which mate with standard trunnion fittings on large satellite elements. The OMV and OTV hangars will include similar beam assemblies.

Utilities will be brought to the service/storage facilities from the main utilities busses, as for modules.

The OMV and OTV hangar doors will be provided with conventional hinge, latch, and drive mechanisms. The satellite servicing area does not include doors.

3.3.3.5 Thermal Control Concept Evaluation

3.3.3.5.1 Introduction

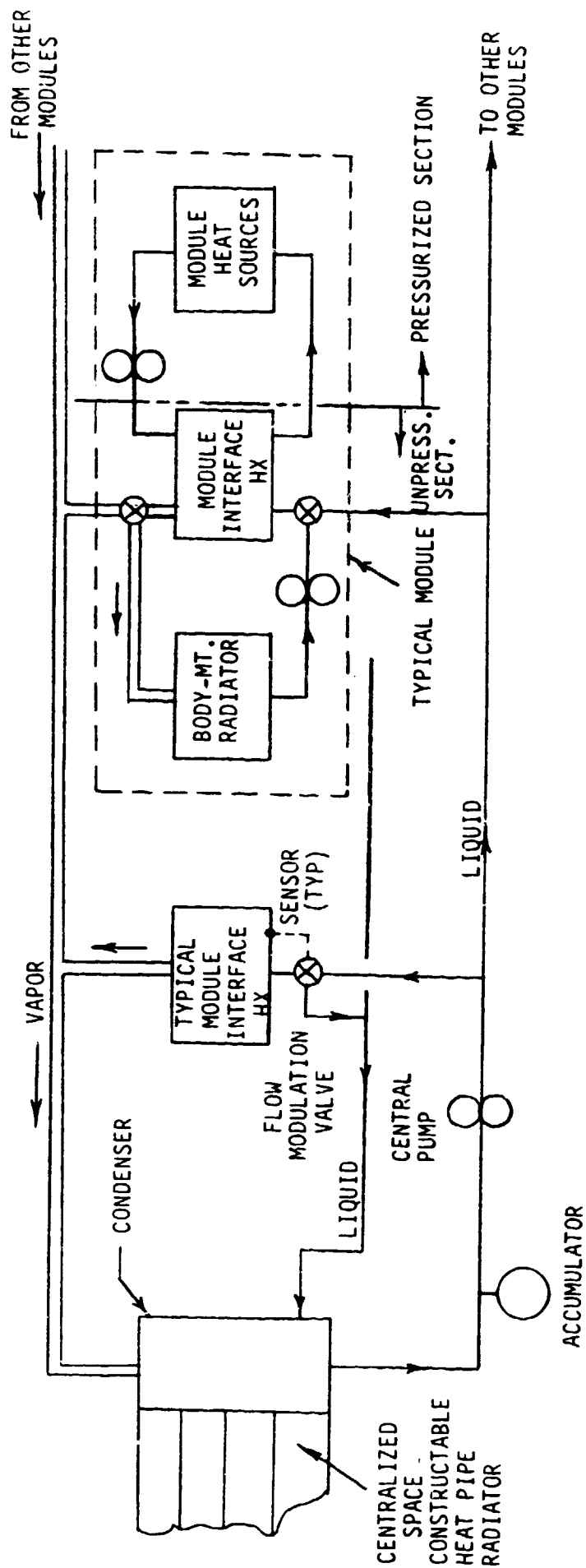
Engineering evaluation considerations during this study were:

- o Vehicle thermal environment (i.e., view factors, blockage, heat fluxes)
- o Radiator area requirements
- o Orbiter impacts
- o Design complexity
- o Verification complexity
- o Surface contamination sensitivity
- o Hardware commonality
- o Technology status

The following discussions will present a system overview and will assess how well the delta vehicle configuration satisfies these factors.

3.3.3.5.2 System Overview

The candidate Active Thermal Control Subsystem (ATCS), schematically illustrated by figure 3.3.3.5-1, is a hybrid design concept that maximizes the use of local thermal control for individual station modules and satisfies the remaining thermal control requirements with a centralized system. Each station module will contain a heat collection and transport system similar in function to the Shuttle Orbiter cabin design (i.e., a pumping system, coldplates, heat exchangers, plumbing lines and flow control valves). These individual station module systems will be integrated with a central transport



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Figure 3.3.3.5-1. Active Thermal Control Subsystem Concept

system. In addition, each station module will have heat pipe space radiators (operating at about 70°F) integrated with the module meteoroid protection shield. The size of these radiators will vary from module to module depending on surface area availability considering docking ports, windows, thermal blockage, etc.

When waste heat in a station module exceeds its thermal capacity, the excess heat will be transferred to a central collection and transport circuit for delivery to a central truss-mounted deployed radiator attached immediately above the station modules. A separate high temperature radiator (operating at about 160°F) will be attached to the truss near the solar array to reject electrical power system waste heat from the regenerative fuel cells and electrolysis units. Because the transport circuit (or "thermal bus") uses a two-phase working fluid that transfers heat by evaporation and condensation rather than by sensible heat changes of a single phase coolant, it operates at a constant temperature over the entire length of the loop. Furthermore, this "thermal bus" is capable of transporting large thermal loads over long distances with pumping requirements that are very small compared to single phase fluid systems. Table 3.3.3.5-1 summarizes the IOC weight and power estimates for the candidate ATCS concept.

A vehicle thermal system design which judiciously applies thermal coatings, vacuum type insulations, isolators, and heaters will be selected for those systems and elements which are not integrated into the ATCS. The system will be selected to minimize the addition of electrical heat for thermal control purposes. The systems which appear to require such a design, at this time, are the communications (antennas), propulsion remote manipulator, and control

Table 3.3.3.5-1. IOC Active Thermal Control
Subsystem Characteristics

STATION ELEMENT	WEIGHT (LBS)		POWER (KW)
	DRY	WET	
C/C ₁	1,345	1,465	0.33
LAB ₁	2,621	2,945	0.89
LAB ₂	1,803	2,002	0.52
HAB ₁	2,452	2,591	0.33
LOG ₁	485	514	0.06
MODULE* TRUSS	6,113	6,243	0.22
POWER SYSTEM TRUSS**	3,057	3,187	0.16
TOTALS	17,876	18,947	2.51

*TRUSS-MOUNTED RADIATORS AND ASSOCIATED TRANSPORT SYSTEM LOCATED
ADJACENT TO STATION MODULES.

**TRUSS-MOUNTED RADIATORS AND ASSOCIATED TRANSPORT SYSTEM LOCATED
ADJACENT TO SOLAR ARRAY.

moment gyros. Heaters in these systems will eliminate thermostats and their inherent failure modes by using sensors to feed software logic for heater control.

An insulation/coating system will be selected for the habitable areas and power generation systems which compliments the active heat rejection systems. Insulations and coatings will be applied to unpressurized areas such as the satellite service structure, OMV and OTV hangars in order to bound the thermal environments within the payloads design envelopes thereby minimizing operation of the payload thermal/control systems and station power requirements.

The solar inertial orientation of the delta configuration and the solar shading provided by the solar panels provides an opportunity to apply thermal surface treatments with the potential for minimal degradation and refurbishment. Treated metal finishes (alodined or anodized) can be selected with a wide range of emissivities (0.10 to 0.72) for those surfaces which do not receive direct solar energy. Some controls and dynamics approaches being considered will result in long term solar exposure on portions of the station elements. These elements, such as the radiators, will require low solar absorptivity (α) and high emissivity (ϵ) coatings which cannot be achieved with the treated metals since the absorptivity tends to increase with emissivity.

The insulation system is envisioned as similar to the high performance multilayer insulation design applied to the Orbiter vehicle except having as many as 20 layers of organically coated aluminized film as opposed to the 10 layers in the Orbiter design. This would result in a weight of approximately 0.25 pounds per square foot including mesh separators, attachments, venting provisions, and cover material. The insulation weight for the delta IOC and growth configurations are 5,300 and 12,425 pounds respectively.

Local protection from RCS engines plume heating will be required. The extent of the protection and its impact on design will depend on engine firing requirements.

The propellant tanks of the monopropellant hydrazine propulsion system will be individually mounted on the command module and each will be maintained within temperature limits through passive thermal control. For the hot environment, each tank (3.5 foot diameter) will be maintained below its upper temperature limit by use of insulation and an appropriate coating. For the cold environment, each tank and the fuel distribution system will be maintained above its lower limit by the use of insulation and heaters. The heater wattage needed for this purpose is shown in table 3.3.3.5-2.

Preliminary design indicates that the 25 pound thrusters will be placed in clusters of 12 thrusters each and will be mounted on the command module next to the propellant tanks. Passive thermal control of the thrusters and their feedlines will be achieved through insulation of the cluster and the use of heaters for the engines and lines. Heater wattage needed is shown in table 3.3.3.5-2.

The thermal control heaters for the propulsion system are sized based on a 50% duty cycle.

TABLE 3.3.3.5-2
PROPULSION SYSTEM HEATER REQUIREMENTS

CONFIGURATION	TANKS & FUEL DISTRIBUTION			THRUSTERS & FEEDLINES	
	# TANKS	TOTAL AREA FT	HEATERS WATTS	# THRUSTERS	HEATERS WATTS
△ - IOC	8	308	862	24	960
△ - GROWTH	12	462	1293	48	1,920

The passive thermal control design of the antennas is similar to that of the Orbiter Ku-band antenna. Each electronics box will be of minimal thickness with the electronics mounted directly to a cold plate radiator located on the large face of the box. The box will be covered with silvered teflon with an absorptance/emittance (α/ϵ) = .13/.8 . The radiator area for each electronic box and internal heat generation for each different type of antenna is shown in table 3.3.3.5.-3. Also shown in this table is the heater wattage needed in each electronic package to keep the electronics above their minimum temperature.

The heater wattage needed to maintain the gyros, gimbals, and comparator of the S/Ku-band steerable dishes above their minimum temperatures are shown also in table 3.3.3.5.-3. The heaters for maintaining minimum temperatures are sized based on a 50% duty cycle. Antenna heater operation will only occur when the antenna is off two hours or more.

TABLE 3.3.3.5-3
IOC DELTA ANTENNA THERMAL CHARACTERISTICS

ANTENNA TYPE	ELECTRONICS PACKAGE FOR EACH ANTENNA					TOTAL THER. CONT. HEATERS WATTS	ANTENNA COMPONENTS THERMAL CONT. HEATERS	
	NO	TEMP LIMITS F°	INT. HEAT GEN. WATTS	RADIATOR AREA FT ²	THERMAL CONT. HTRS* WATTS		EACH ANTENNA WATTS	TOTAL WATTS
S-BAND MED GAIN P.A.	1	32-131	335	11.2	525	1,575	---	---
K-BAND HIGH GAIN MULTI P.A.	2	32-131	250	8.4	394	1,182	---	---
K-BAND MED GAIN P.A.	1	32-131	175	5.9	277	---	---	---
S/KU-BANDS STEERABLE DISH	1	130-152	250	8.4	394	1,182	230	690
L-BAND WIDE BEAM	1	0-191	45	1.5	70	210	---	---
K-BAND HIGH GAIN P.A.	2	32-131	85	2.8	131	786	---	---
TOTAL						4,935		690
GROWTH DELTA ANTENNA THERMAL CHARACTERISTICS								
S-BAND MED GAIN P.A.	1	32-131	335	11.2	525	1,575	---	---
K-BAND HIGH GAIN MULTI P.A.	2	32-131	250	8.4	394	1,182	---	---
K-BAND MED GAIN P.A.	3	32-131	275	5.9	277	831	---	---
S/KU-BANDS STEERABLE DISH	1	130-152	250	8.4	394	1,182	230	690
L-BAND WIDE BEAM	1	0-191	45	1.5	70	210	---	---
K-BAND HIGH GAIN P.A.	10	32-131	85	2.8	131	2358	---	---
* HEATERS SIZED FOR 50% DUTY CYCLE						7,338		690

3.3.3.5.3 Technical Evaluation

3.3.3.5.3.1 Thermal Environment

The Delta Space Station configuration orbits in an attitude with the solar array inertially pointed towards the sun. This results in the majority of the station structural elements being shaded from the sun by the solar array throughout the orbit. As a consequence of this, thermal coating performance (solar absorptance/infrared emittance) of these shaded elements need not be optimal. However, modules and radiators in close proximity will exchange heat through radiation so IR optical properties would be tailored to properly balance the system.

Orbital average incident thermal flux levels at $\text{Beta} = 0^\circ$ are shown for the delta configuration in figure 3.3.3.5.2. Analysis was accomplished at the 0° Beta due to previous studies having shown that increased Beta angles, up to 52° , did not appreciably alter incident flux level averages for this configuration. Quantities for the modules are indicative of the flux levels on the areas where body-mounted radiators would likely be placed; that is, on 50% of the module circumference away from the trusswork. Fluxes given for the hangar are for the exposed ends only.

As shown, flux levels on most elements are relatively low, enhancing the capability for waste heat rejection. However, one command/control module will have a large amount of incident solar flux impinging on a portion of its surface, so a low (α/ϵ) thermal coating would be required.

Average form factors to space, using the previously mentioned assumptions, are shown in figure 3.3.3.5-3. The difference between these factors and a factor of 1.0 gives an indication of the amount of blockage a surface receives from other structures. The high view factors indicated in figure 3.3.3.5-3, along with low environmental thermal fluxes, imply little blockage and good

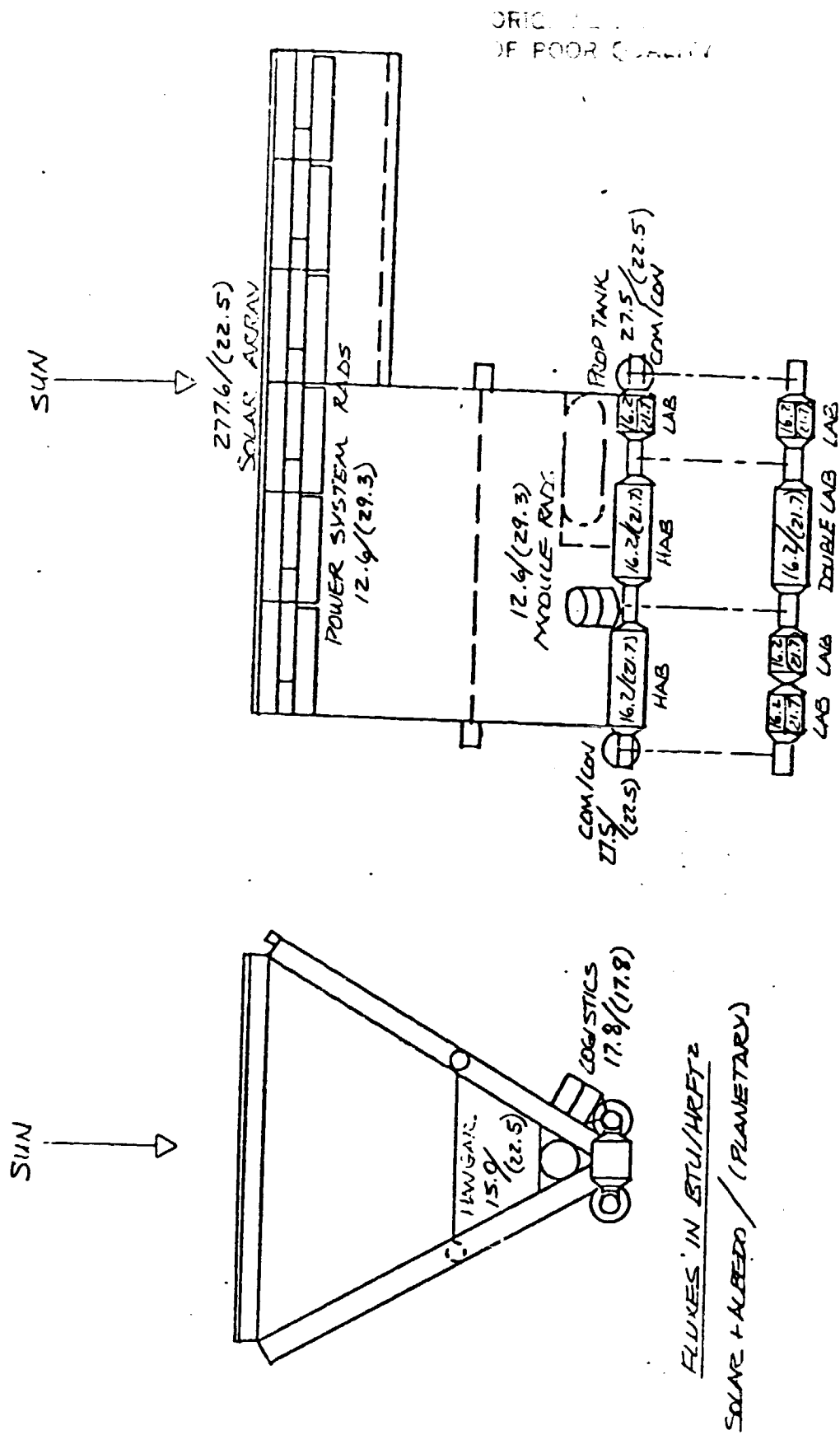


Figure 3.3.3.5-2. Delta Configuration Orbital Average Thermal Fluxes; Beta=00

capability for heat rejection to space for exposed radiator areas.

Since body-mounted radiators are assumed to be encompassing only the most favorable 50% of a module surface, sensitivity to interaction with other modules and structure is reduced, especially with a "thermos bottle" type insulation system. Placement of planar radiators on the truss surface implies single-sided heat rejection, though some backside heat rejection may be desirable from the module radiators to maintain the hangar internal temperature within a required range.

Areas internal to the Delta truss structure will be thermally influenced by the back surface of the solar array which will be operating at approximately 150°F to 170°F during the sunlit portion of the orbit. The array should cool to -75°F during the night portion.

During buildup of the delta configuration, the solar arrays should be placed to shade the modules and deployed radiators from the sun in order to prevent excessive incident thermal fluxes. If this is done, the IOC and growth versions of the station should have similar thermal characteristics.

3.3.3.5.3.2 Radiator Areas

Radiator area requirements initially were defined for body-mounted radiators (integrated with station module meteoroid protective shields) to determine heat rejection capabilities for each station module. In general, the effectiveness of the body-mounted radiators is excellent since blockage from surrounding vehicle elements is almost nonexistent as discussed in paragraph 3.3.3.5.3.1. However, it was assumed that 50% of the cylindrical station module wall area was not available for radiators due to interfacing structure with the truss. As a result, body-mounted radiators reject about 30% of the station total waste heat as summarized in Table 3.3.3.5-4.

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Table 3.3.3.5-4
BODY-MOUNTED RADIATOR HEAT REJECTION CHARACTERISTICS*

STATION ELEMENT	IOC			GROWTH		
	WASTE HEAT LOAD (KW)	REJECTION CAPABILITY (KW)	AVAIL AREA (FT ²)	WASTE HEAT LOAD (KW)	REJECTION CAPABILITY (KW)	AVAILABLE AREA (FT ²)
C/C ₁	9.8	5.9	323	10.1	5.9	323
C/C ₂	--	--	--	8.2	5.9	323
HAB ₁	8.6	16.4	807**	10.1	16.4	807**
HAB ₂	--	--	--	8.5	16.4	807**
LAB ₁	45.5	6.6	323	46.0	6.6	323
LAB ₂	24.5	6.6	323	25.0	6.6	323
LAB ₃	--	--	--	36.2	16.5	807**
LAB ₄	--	--	--			
LAB ₅	--	--	--	18.1	6.6	323
LAB ₆	--	--	--	18.1	6.6	323
TOTALS	88.4	35.5	1776	180.3	87.5	4359

*Total vehicle waste heat loads: 137KW (IOC)
(Neglecting Comm/Tracking) 277KW (Growth)

**Long Module

Truss-mounted one-sided radiator panels were sized to reject the balance of the vehicle waste heat not accommodated by the body-mounted radiators. For IOC, truss-mounted radiators with a total radiating area of 3,641 ft² are required to reject the balance of the station module heat loads. A separate set of truss-mounted radiators (operating at about 160°F) are located near the solar array to provide electrical power system heat rejection. Area requirements for the power system radiators are 1,325 ft². For the growth station, the truss-mounted radiators for the station modules increase to 6,216 ft² and to 2,639 ft² for the power system.

The aforementioned radiators were sized to reject the total vehicle waste heat load. Past studies have shown that the use of a thermal storage phase change material can further reduce area requirements when large temperature transients are encountered. These transients normally result from widely varying environmental heat fluxes and/or internally generated vehicle waste heat. For this study, the power system radiators were selected to illustrate the potential application of thermal storage.

Because of the difference in day/night times and the difference in efficiencies between the fuel cell modules and the electrolysis modules, the night time heat load for the power system is much greater than the day time heat load. As mentioned, if part of the night time heat can be stored in a phase change material for rejection during the day time, the power system radiator area can be reduced further. One candidate for a phase change

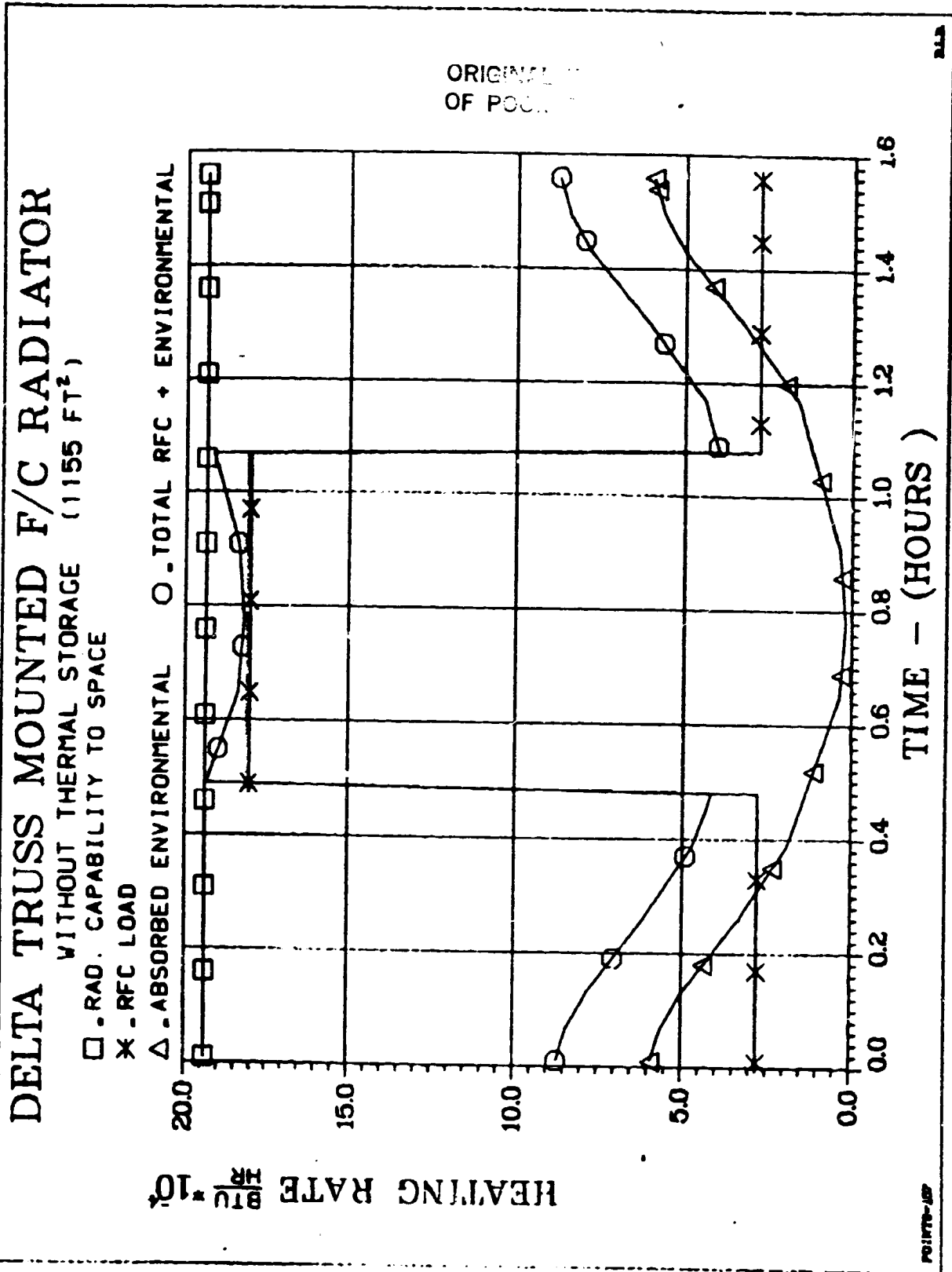


Figure 3.3.3.5-4

DELTA TRUSS MOUNTED F/C RADIATOR

WITH THERMAL STORAGE (593 FT²)

□ . RAD. CAPABILITY TO SPACE

× . RFC LOAD

△ . ABSORBED ENVIRONMENTAL

○ . TOTAL RFC + ENVIRONMENTAL

HEATING RATE
BTU / HR × 10⁴

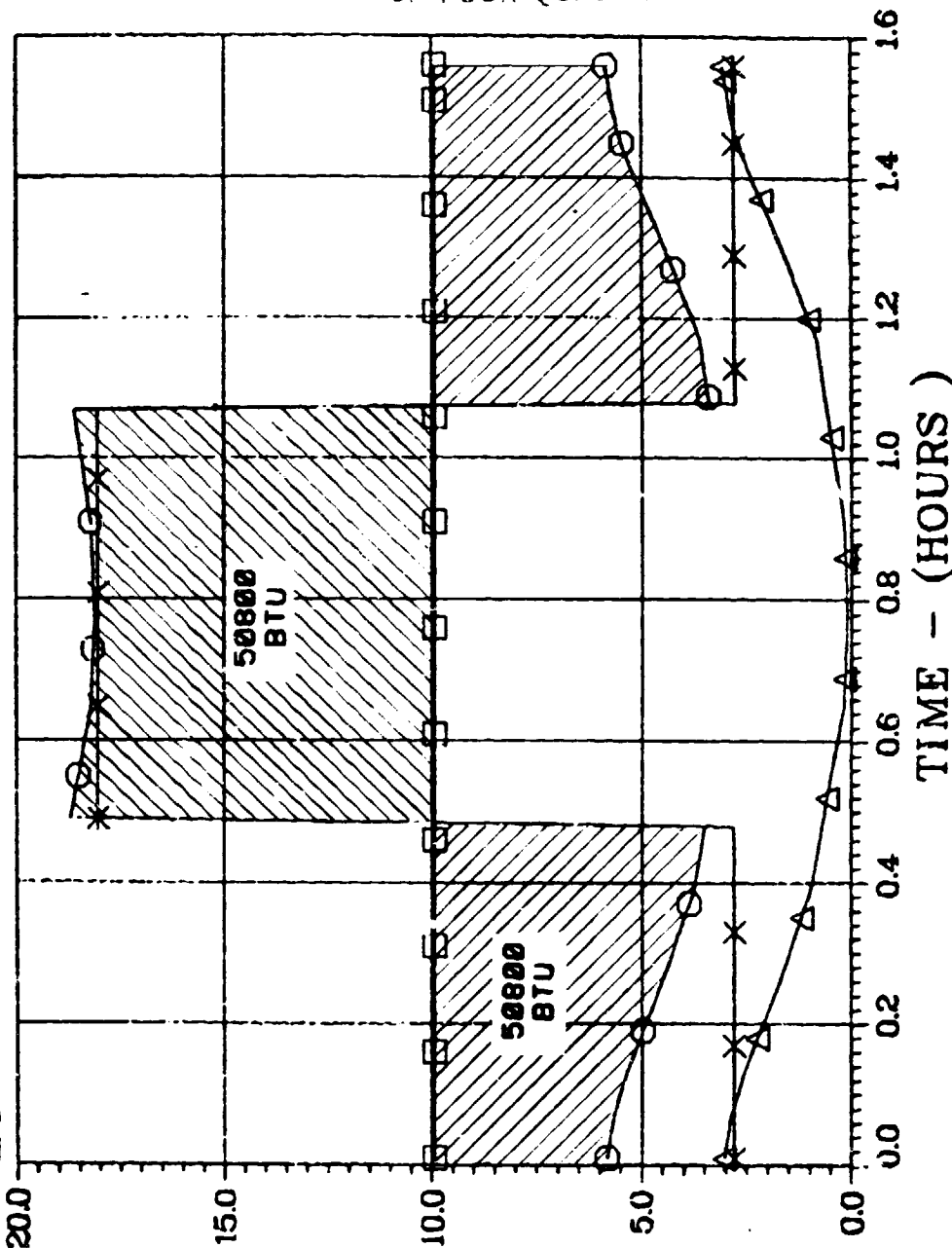


Figure 3.3.3.5-5

thermal storage material for the regenerative fuel cell heat rejection system is Barium Hydroxide Octahydrate. Its density is 136 lb/ft³, melting point is 172°F, and latent heat is 129 btu/lb.

Preliminary analysis shows that the use of 394 lb. of this phase change material would reduce the required remote radiator area by about 50%*.

Required radiator area and capability and applied heating loads without and with thermal storage are shown in figures 3.3.3.5-4 and 3.3.3.5-5 respectively. Although the weight of the phase change material and associated hardware will probably be equivalent to the radiator weight reduction, other design considerations such as view factors and blockage may still favor the use of thermal storage material. In addition, a thermal storage approach permits a non-articulated radiator to be a viable station option.

(* Power system waste heat characteristics used in the thermal storage evaluation were not the same as used in the final radiator sizes documented earlier; however, the general conclusions reached and relative savings demonstrated are valid.)

3.3.3.5.3.3. Orbiter Thermal Control Impacts

Potential Orbiter thermal design impacts exist for the main landing gear dump valve and strut actuators for all docked attitudes on the delta configuration. The Orbiter attitudes are currently constrained to prevent exceeding the lower performance limit of -35°F for these components. A preliminary pre-entry heater design exists which would eliminate the constraint.

While the Shuttle Orbiter is docked to the station, heat rejection from the Orbiter radiators is reduced about 15% due to blockage from surrounding station elements. This reduction is considered acceptable since the Orbiter probably will be powered down the majority of the time.

3.3.3.5.3.4. Design Complexity

The primary design complexity involves the launch packaging on-orbit construction and activation of the truss-mounted radiators. This operation will require RMS to:

1. Remove radiator contact heat exchanger modules and radiator elements from the Orbiter payload bay
2. Install contact heat exchanger modules on the station truss,
3. "Plug in" radiator elements into the contact heat exchanger. EVA support probably will be required to make final fluid line connections.

3.3.3.5.3.5 Verification Complexity

Component level verification should follow that of previous programs with the possible exception of life cycle tests. Items which fall into this category are insulations, coatings, heater system components, and fluid distribution system components. These tests with the possible exception of the heat pipe radiators do not appear any more complex than those of past programs.

The question of verification complexity in the thermal area arises from

verification of the integrated thermal control design of the Space Station. The recommended approach is to baseline ground thermal testing of typical elements and interfaces based on design commonality (to the fullest extent possible) supplemented by Orbiter in-bay or deployed testing of items such as heat pipe radiators requiring unique environments. Testing during the Space Station buildup would be limited to checkout type tests. Since the thermal verification approach is not highly configuration dependent, additional discussion is presented in the Subsystem Definition Section, section 4.2.

3.3.3.5.3.6 Surface Contamination

Contamination of thermal control surfaces resulting from RCS engine plume impingement and other effluent sources can be accommodated in the thermal system design and selection of materials. As discussed previously, the Delta configuration provides the potential for material selection with minimum dependence on solar absorptivity properties and which in most cases would require a high emissivity value. In general, contamination tends to increase the emissivity. The location of the solar panels and radiators with respect to the RCS system appears to provide adequate protection.

3.3.3.5.3.7 Delta TCS Commonality

o Within Space Station

The delta Space Station configuration is an inherently symmetrical structure with the habitat and lab modules being arranged symmetrically about one apex. This results in similar thermal environments being imposed on both strings of modules when averaged over the Beta angle cycle throughout an orbital year. This similitude of external influences permits a design of the thermal control subsystem that will be closely replicated from module to module. The primary

variables will be the amount of internal equipment requiring thermal control and the consolidated heat load to be rejected from each module.

Most modules will use the same hardware architecture for passive (coatings, insulation) and active (heat acquisition, transport, utilization, rejection) thermal control. The possible exceptions to this will be the command control modules which are not mounted adjacent to a planar truss surface and which have higher incident solar flux. A dedicated, deployed radiator would not be feasible at their location so the thermal load must be assumed by other modules or be transported to a radiator location on one of the truss faces. The impact of this would be dependent upon the amount of load-sharing capability or thermal bus utilization that was designed into the system initially.

Power system thermal control elements will also experience similar thermal environments so the TCS design will be duplicated as the power requirements expand. Design duplication will in general, also be inherent in the TCS of antennas and RCS engine moduels.

o Commonality with platform

Specific thermal control system hardware components (insulation, cold plates, heat exchangers, radiators, etc) from the delta Space Station could readily be incorporated into a free-flying platform. Basic thermal bus architecture would also remain the same or similar if the platform were to require a large thermal control capacity. The greatest divergence from the Space Station TCS would be in heat rejection. If a module concept is utilized in the platform, module-mounted radiators would most probably be used. However, a deployed auxiliary radiator surface may be required to be articulated, depending upon the platform orbital attitude. If the articulation of radiators is required, a fluid swivel or thermal slip ring, which is not requisite for delta Space

Station heat rejection must be developed.

The utilization of high performance thermal coatings could be more critical on the platform than on the delta station. This is assuming that the platform is not oriented inertially towards the sun and is not the same configuration as the station, thereby allowing greater solar impingement on associated structural elements. The degree of thermal coating performance is dependent upon the actual platform configuration and orbital attitude.

3.3.3.5.3.8 Technology Assessment

No vehicle unique technology requirements were identified. The on-going OAST sponsored thermal technology program is further discussed in section 4.2.2.8.

3.3.3.6 Power System Evaluation

3.3.3.6.1 Introduction

The Power System consists of three subsystems: Energy Conversion Subsystem (ECS), Energy Storage Subsystem (ESS), and Power Management and Distribution subsystem (PMAD). For the Delta Truss configuration, the power system was designed to supply an average of 75 KW at IOC and 150 KW for the growth station phase. The system was designed with the following groundrules:

1. Ten year operational life was a design goal used for the various components.
2. A modular buildup scheme was used where practical.
3. Module changeouts were permitted to achieve the 10 year operational life of the components and the extended life of the station.
4. EVA was minimized for buildup but was not prohibited.
5. A two hour period was baselined for an emergency energy storage sizing criteria. This would allow for the loss of one complete charging cycle.

6. Some off axis pointing was allowed to account for the flight attitude of the truss. As a result, the array size was increased by approximately 10%.

3.3.3.6.2 System Overview

The ECS solar array for the delta truss will occupy one face of the triangle. The array will be attached to the truss which provides structural support. The array will be launched in a box-like container, attached to one edge of the truss, and then deployed. The blanket will be attached to the face of the truss. The initial truss area only accommodates enough solar array to satisfy IOC power requirements. Additional truss will be added to accommodate the solar array area necessary to satisfy the growth station power requirements. The ESS/PMAD module will be located at one edge of the truss adjacent to the array. It will be attached so that the thermal control radiators can be mounted on one side of the module. Since the station is solar oriented, the array and radiators are fixed in a single position. The PMAD equipment is located in this module and only high voltage, high frequency AC power is transmitted to the other parts of the station. The basic arrangement is illustrated in figure 3.3.3.6.2-1.

A breakdown of the weights is shown in table 3.3.3.6.2.-1. It was assumed that the truss weight is not chargeable to the ECS solar array.

The delta truss configuration provides a very convenient installation location for the solar array. With this configuration the mast will not be utilized. However, a mechanism will be provided to deploy the array (a cable/pulley arrangement may be used). The other parts of the array are common to all configurations, i.e., the box, blanket, wire guides, etc. (see figure 3.3.3.6.2-2. Also, some means of attaching the blanket to the truss will have to be developed. This should not be a major problem but will have to be considered.

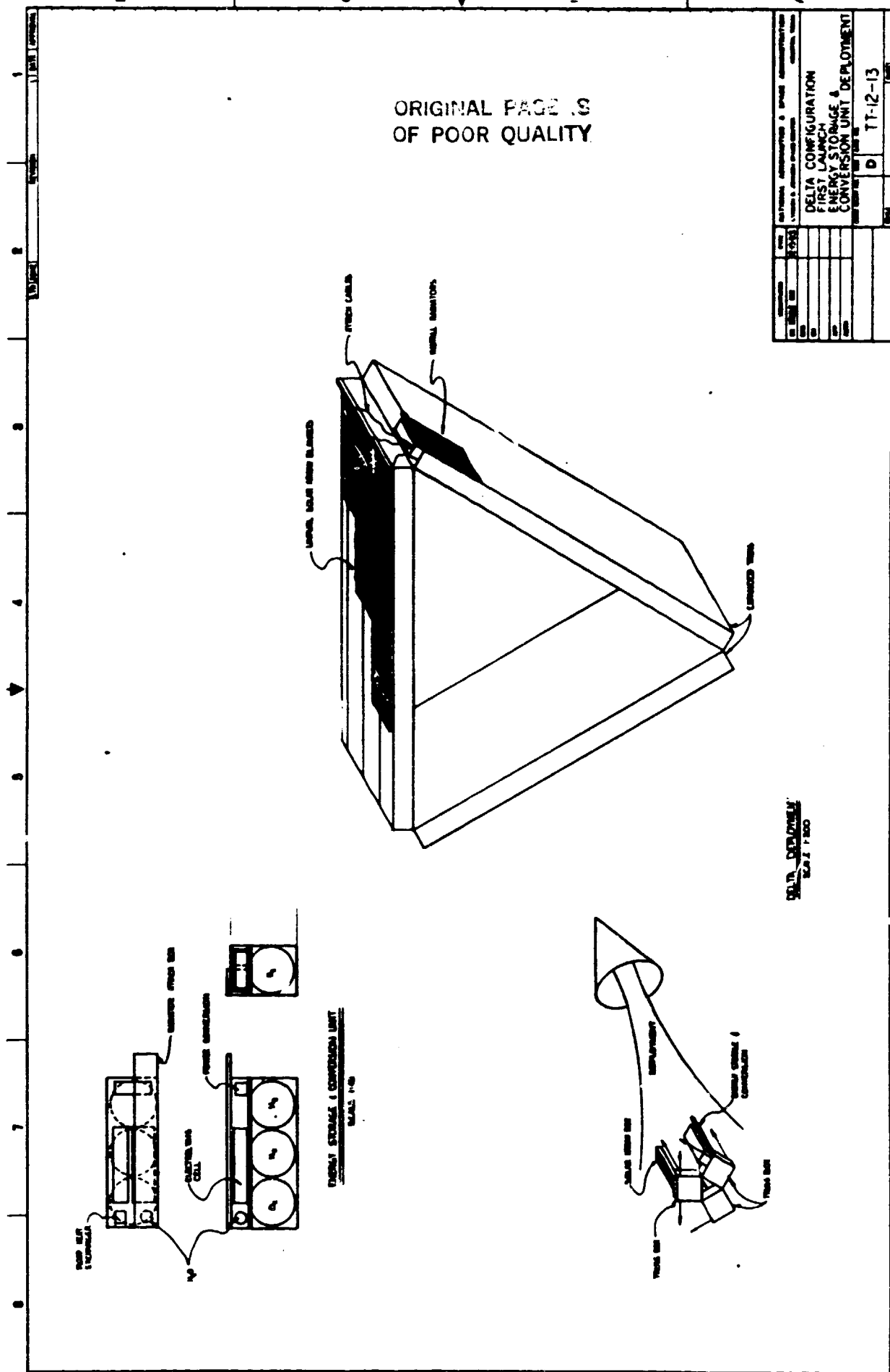


Figure 3.3.3.6.2-1

Table 3.3.3.6.2-1. Delta Truss Power System Characteristics

SOLAR ARRAY (ECS)

	Weight (lbs)	Area (ft ²)
IOC	5,469	18,229
Growth	10,937	36,458

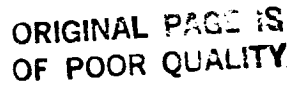
REGENERATIVE FUEL CELL (ESS)

	Weight (lbs)
IOC	3,967
Growth	7,933

PMAD

	Weight (lbs)	Volume (ft ³)
ESS/PMAD Module	210	1.34
Habitat Module	362	6.70
Logistics Module	221	3.53
Laboratory Module	372	6.56
Command/Control Module	1,978	23.64

FIGURE 3.3.3.6.2.2 SOLAR ARRAY ELEMENTS



BACK SIDE

The delta will not always fly with the array perpendicular to the solar vector and therefore, the size was increased by roughly 10%. This was done to minimize the control propellants required and to allow more freedom in c.g. control.

From only a solar array perspective, the truss provides a very convenient structure for mounting a solar array.

3.3.3.6.3 Technical Evaluation

The following items should be considered for the delta truss configuration:

1. The array for this design will be about 10% larger than for a totally solar oriented station.
2. Since there are no moving joints, the structure associated with the array will be minimized. Note that there will be no moving electrical or fluid joints.
3. This configuration would be very compatible with a solar dynamic system that might be available in the future. The truss might also serve as a mounting platform for GaAs concentrator arrays. However, concentrator arrays require precise solar orientation of $\pm 2^\circ$.
4. The arrays are located such that shadowing and plume impingement problems should be minimized.
5. The power will be transmitted approximately 125 feet from the ECS/PMAD module to the station modules. This cable will have to be installed after the truss is erected.
6. If the station were to fly in a gravity gradient mode, then some power would still be available.
7. The ESS/PMAD module is located adjacent to the array to minimize the distance that the DC power must be transmitted.
8. Since all the power system components are mounted externally, EVA's will probably be required for module changeout.

9. The ESS composed of RDC's does not comply with the man-rated redundancy specification until the third ESS/PMAD module is installed.

3.3.4 Operation Evaluation

3.3.4.1 Configuration Design Considerations

3.3.4.1.1 Separation from the Space Station

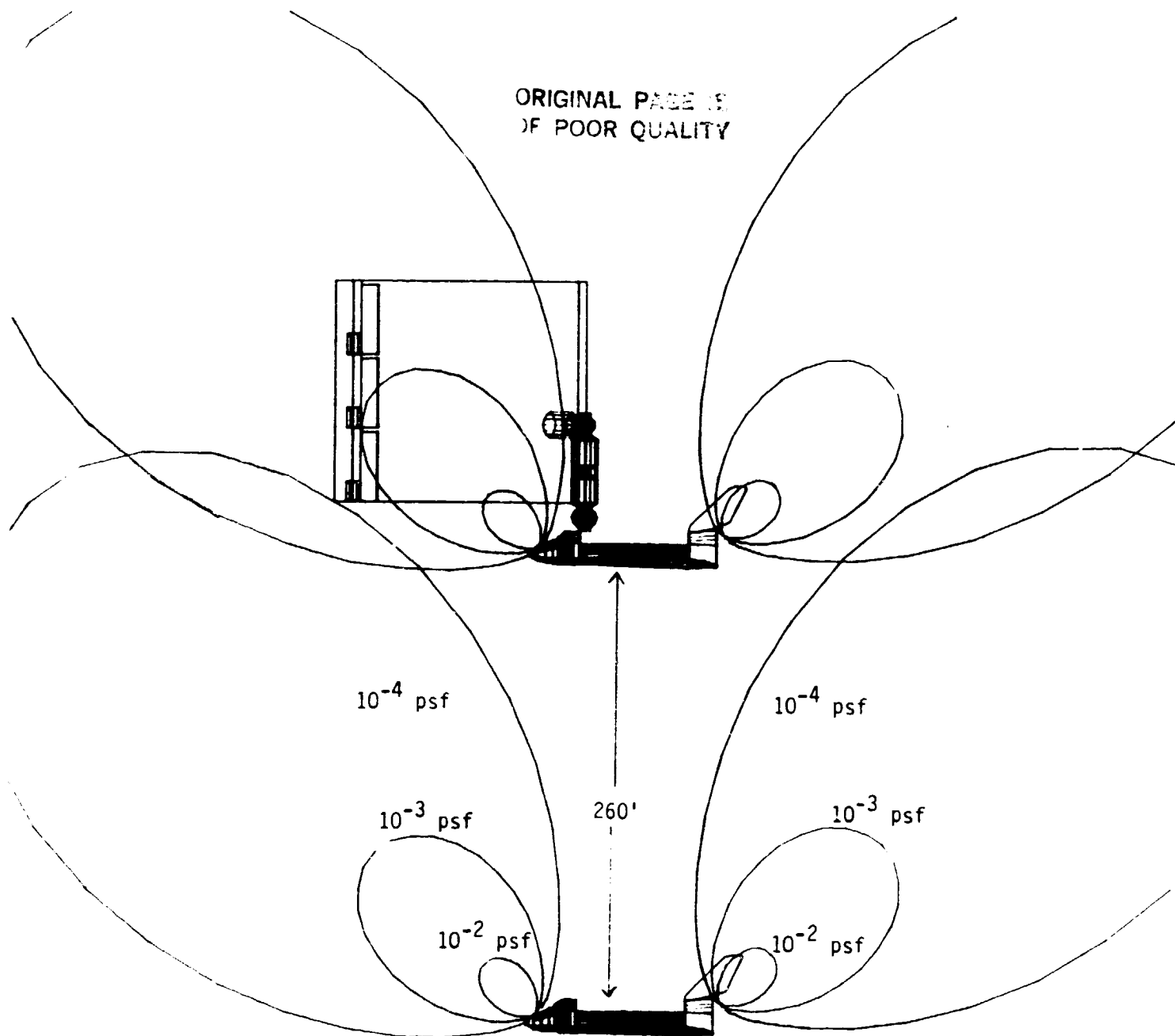
The location of the docking ports (2) on the IOC of the Delta Space Station are illustrated in figure 3.2.4.1-i. The solar inertial attitude utilized by the delta requires that its solar arrays always face the sun. The separation sequence described in section 4.11, when applied to the velocity and radius vectors, represents a sequence entirely feasible for the delta configuration. The only specific requirements is that time must be allowed for the delta to rotate such that its ports are on or near the one of the two respective axes prior to initiation of the sequence.

3.3.4.1.2 Return to the Space Station

The return scenario to the inertially stabilized delta configuration may be accomplished using any of the approach techniques described in section 4.11. However, the farmost choice would be the inertial approach. Also, allowing for sufficient rotation of the delta station and its ports would make approaches along the velocity or radius vectors feasible as shown in figure 3.3.4.1-1. However, this would imply additional timing and lighting constraints.

Additional concerns may arise from the delta configuration due to the two ports being located essentially side by side. If two vehicles are to be docked simultaneously to the station, clearance may become a problem during the separation or approach for the last of the two vehicles to leave to arrive. Placing the two vehicles in a "nose-to-nose" orientation may alleviate the problem. Also, the capability to rotate the ports may be

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Note: Figure assumes one nose and two tail VRCS jets added to Orbiter canted 45° from vertical.

Figure 3.3.4.1-1. VRCS Plume Dynamic Pressure Contours
(Delta Truss Configuration)

desirable. However, in the case of a single vehicle leaving or arriving at the station, clearance from the station itself does not appear to be a problem.

3.3.4.2 RMS Reach Capability

An integral subsystem of the Space Station will be one or more manipulators remotely operated and used to perform a variety of operations. Some of the more critical requirements of a station manipulator will be station assembly, module removal, OMV/OTV berthing in the hangar area, deployment of the OMV/OTV from the hangar area, as an aid to OMV, OTV, and satellite servicing, and possibly as an aid to Orbiter/station berthing. The analysis conducted in support of this document emphasized the use of the current Shuttle RMS to the maximum extent possible for assembly of the delta concept. A "special" station manipulator was considered only for those operations which exceeded the reach capability of the Shuttle RMS.

The RMS analysis was performed using the RMS Desk Top Planning (RPS) developed for RMS mission planning activities and used to define RMS payload handling capabilities and procedures for STS missions. The program was updated and modified to include the delta configuration.

The manipulator analysis included herein, is based on a kinematic model of the RMS in that no rigid or flexible body dynamics are included. This limitation, however, does not invalidate the feasibility of using the RMS for station assembly since all modules handled are within the weight and inertia limits verified for standard RMS operations. The study results are based on the current RMS control algorithms and software and verify the reach capability as well as the maneuver path for the RMS. The simulation also checks for singularities and joint reach limits. In summary, all maneuvers studied for the Delta configuration assembly sequence should be valid with the exception

of possible crew visibility constraints. RMS operator eye-point and CCTV views can also be generated using the RPS simulation, and these results will be reported in future documentation.

In performing the kinematic analysis to assess the RMS capability to remove station modules from the Orbiter payload bay and assemble the station, the following assumptions were used.

1. Truss structure is assembled prior to module deployment.
2. Port and starboard RMS's are available
3. Once the C/C module and an interface module are attached to the truss structure, all remaining construction using the Orbiter RMS's will be accomplished with the Orbiter firmly docked to the Space Station.
4. Grapple fixture location and orientation are identical on all modules of the same type.
5. Payload bay locations consider only RMS reach capability and not Orbiter c.g. restrictions.

The similarity in the module arrangement of the Delta configuration to that of the big "T" results in essentially the same assembly scenario as described in section 3.4.4.2 for the big "T." The only exception is that preliminary analysis indicates there is no single location available for a station manipulator (SM) such that the logistics module, the last two interface modules and tunnel can be maneuvered into place. In general, the reach analysis of a station manipulator on the Delta configuration is complicated by the double truss arrangement forming the sides of the Delta to which the modules are attached. Future analysis will attempt to define an optimum single location for the SM which can accommodate station assembly and operations.

3.3.5 Safety Accommodations

The safety accommodations provided for the IOC Phase (Phase I) were used for the basic concept evaluation since this was considered the most critical with respect to crew safety. In the growth phase, volume available increases the time of reaction to a leak of approximately 1.0 hours (see paragraph 3.3.5.5). Otherwise, the comments are applicable to both Phase I and Phase IV.

3.3.5.1 General

The Delta truss configuration does not appear to present any constraints to meeting the requirements for crew safety, assuming the requirements specified in Books 3 and 6 of the Space Station Configuration documents are observed.

3.3.5.2 All Habitable Modules (Habitat, Laboratories, Interface and C/C) Egress Capability

Dual egress paths from each module are incorporated. A backup command and control facility will be in the Habitat Module.

3.3.5.2.1 Logistics Module

Book 3 Systems Requirements and Characteristics specifically exempts the logistics module from the "two or more entry/egress paths." The logistics module has only one egress path, the risk to a crewmember occupying this volume during the occurrence of an accident forcing evacuation of the volume could probably be reduced to an acceptable level by proper location of equipment, adequate materials control, elimination of potential ignition sources, and maintenance of adequate traverse clearance during operations in the module.

3.3.5.3 Enclosure of High-Pressure or Hazardous Fluid Tanks

The logistics module will be divided into a pressurized section and an unpressurized section. High pressure and hazardous fluids will be transported in the unpressurized section to avoid the possibility of fluids propagating into other modules or cause overpressurization of one or more modules. The separation distance of various tanks has not been defined.

3.3.5.4 Isolation of Modules after Accident Occurrence

One problem that arises from the provision of dual egress routes from a habitable module is the complexity of the process of sealing off that module after such things as a spill of a toxic fluid. This suggests the desirability of a self-contained environmental control circulation system for modules such as the laboratories to minimize the potential for cross-contamination of modules while the hatches at each end of the contaminated module are being closed.

3.3.5.5 Reaction Time after Occurrence of a Leak

The Safety Division position, with respect to hatch management, is that all hatches should be normally open to create ease of transit from module to module, reduce the wear on hatch mechanisms, prevent hatch opening difficulties because of small pressure differentials, and maintain the maximum volume for bleed down in case of a leak. Of these reasons, the last is probably most significant, considering the large number of sealing surfaces and the increased potential for a leak. In the IOC configuration of the Delta, a rough calculation of the time to react to the occurrence of a leak equivalent to a one-inch diameter hole would slightly less than 30 minutes, assuming a 95 percent efficient orifice, an occupancy of 25% solids in the station, and a reduction of pressure from 14 to 9.1 psia. If a leak detector

sufficiently accurate to determine the module containing the leak is available, this should allow adequate time to react to the occurrence by evacuating and sealing off the affected module.

3.3.5.6 EVA Operations

The RCS package locations were not specified and no evaluation of their effect on EVA operations was possible. The structural approach should be readily adaptable to the provision of EVA traverse and work station restraints.

3.3.5.7 Repair and Reactivation of Modules after an Accident

Adequate airlock provisions are provided to allow Intervehicular Activity (IVA) suited reentry into a module that has been isolated because of an accident to perform necessary repair or reconfiguration to permit continued use of the module.

3.3.5.8 Multiple Orbiter Docking Ports

The ability to dock with and access the Orbiter from various volumes of the Space Station is acceptable.

3.3.6 Cost Evaluation

3.3.6.1 Groundrules and Assumptions

The following groundrules and assumptions were used in the cost analysis for the Delta configuration:

- o The Space Station Cost Model (SSCM) developed by Planning Research Corporation (PRC) was used to develop hardware and system level costs.
- o The concept was treated as one work package.
- o The IOC configuration only was costed.
- o No learning was assumed.
- o No explicit reserve was included.

- o No STS flight costs were included
- o Subsystem costs were allocated to the modules on the basis of weight.
- o Costs are expressed in millions of 1984 constant year dollars. Since SSCM outputs costs in 1982\$, the inflation adjustment was made using the NASA R&D inflation index (1.175 for 1982 to 1984 dollars).
- o Program level costs (including fee) were included using the Code B factors.
- o Complexity factors considered to be 1.0 except the following:
 - o Closed loop ECLS was costed using the open loop ECLS CER with 1.6 complexity factor. Factor based on CDG trade study.
 - o Berthing and docking adapter used a 0.8 complexity factor and used the ASTP adapter as an analogy.
 - o Complexity factor of 0.6 used for fuel cell based on JSC analysis.
 - o GSE complexity factor of 0.8 was used, based on CDG cost estimate.

3.3.6.2 Presentation of Results

Figure 3.3.6-1 presents the results of the SSCM for the Delta approach. The model computes the DDT&E and the first unit costs. The costs shown are for one of each Space Station module or element (i.e., hab module, boom array, etc.) Therefore, figure 3.3.6-1 does not show the total cost of the station. Figure 3.3.6-2 presents the DDT&E and First Unit Costs after being spread to the different modules. The three parts to this figure present cost spreads by module for DDT&E, Production, and total costs. As with the previous figure, the costs shown for the production phase are for the first unit of each of the modules.

Figure 3.3.6-3 presents the summary of the costs by quantities and types of modules that comprise the IOC configuration. The first two cost columns recap

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FIGURE 3.3.6-1

SPACE STATION COST MODEL

DELTA CONCEPT

INFL FACTOR: 1.175 FY84 \$\$ (IN MILLION \$)

SUBSYSTEM	WEIGHT	D&D CMPLX	D&D COST	EQUIV UNITS	TOTAL PROD COST	TOTAL COST
STRUCTURE			575.8		559.5	1135.3
..CUBE	1896	1.00	60.7	4.00	52.1	112.8
..CYLINDER	2641	1.00	73.2	12.00	190.1	263.3
..ENDCAP	931	1.00	40.5	10.00	85.4	126.0
..TUNNEL	1090	1.00	44.4	1.00	9.4	53.8
..TRUSS	3370	1.00	42.5	3.00	24.2	66.7
..SECOND'Y	16069	1.00	214.6	1.32	47.5	262.1
..DOCK ADAPT	600	0.80	10.3	6.00	7.9	18.2
..BERTH ADAPT	600	0.80	10.3	26.00	34.2	44.4
..CMPLX MECH	1912	1.00	50.0	3.63	88.7	138.7
..MECH'ISMS	1644	1.00	29.3	3.71	20.0	49.3
THERMAL	5701	1.00	105.2	4.50	161.2	266.4
6 N & C			159.0		139.6	298.6
..ELECTRONICS	78	1.00	116.8	6.78	88.6	205.4
..CMG	650	1.00	40.3	6.00	45.0	85.2
..MAG TORQ	120	1.00	2.0	3.00	6.0	8.0
RCS	1223	1.00	8.2	2.22	4.7	12.9
POWER			95.0		210.1	305.0
..SOLAR (KW)	66.1	1.00	24.1	3.00	135.7	159.8
..BATT	0	1.00	0.0	1.00	0.0	0.0
..DIST, REG	208	1.00	13.7	12.89	14.5	28.2
..FUEL CELL	1487	0.60	57.1	4.00	59.9	117.0
COMM & DATA	3212	1.00	197.2	3.81	140.8	338.0
ECLSS	5335	1.60	249.5	2.92	171.1	420.7
CREW PROV	1808	1.00	39.2	3.44	26.7	65.9
THRUPUT	0	0.00	0.0	0.00	0.0	0.0
HDW SUBTOTAL			1429.2		1413.6	2842.8
SYS TEST HDW		1.00	1189.1		0.0	1189.1
INST, ASSY, & C/O		1.00	161.3	1.56	156.5	317.9
SYS TEST OPNS		1.00	586.5		0.0	586.5
GR SPT EQMT		0.80	467.6		0.0	467.6
SYS ENGR & INT		1.00	326.7	1.56	105.4	432.1
PROG MGMT		1.00	241.0	1.56	130.3	371.3
SYS TOTAL			4401.5		1805.8	6207.3
PROG SPT (14%)			616.2		252.8	869.0
MGT & INT (5%)			250.9		102.9	353.8
FEE (8%)			421.5		172.9	594.4
PROG TOTAL			5690.0		2334.5	8024.5

FIG. 3.3.6-2A

COST SUMMARY- DELTA CONCEPT

OF POC

DDTE PH-3E

SUBSYSTEM	SUBSYS		COST (MILLIONS OF 84 \$)							
	TOTALS	C/C	HAB	LAB	IM1	A/I.	TRS	DMV	TNL	LOG
STRUCTURE	576	69	111	63	78	56	73	39	44	43
..PRESSURIZED	219	24	43	24	30	30	0	0	44	24
..SECONDARY	257	43	65	34	17	17	43	21	0	18
..DOCK & BERTH	21	1	1	5	6	6	0	0	0	1
..MECH'ISMS	80	1	1	1	24	3	31	18	0	1
THERMAL	105	24	13	57	0	0	11	0	0	0
6 N & C	159	11	2	2	68	77	0	0	0	0
..ELECTRONICS	117	9	2	2	55	50	0	0	0	0
..CMG	40	0	0	0	13	27	0	0	0	0
..MAG TORQUERS	2	2	0	0	0	0	0	0	0	0
RCS	8	8	0	0	0	0	0	0	0	0
POWER	95	5	3	3	0	0	81	0	0	2
..SOLAR ARRAY	24	0	0	0	0	0	24	0	0	0
..BATTERIES	0	0	0	0	0	0	0	0	0	0
..COND & REG	14	5	3	3	0	0	0	0	0	2
..FUEL CELL	57	0	0	0	0	0	57	0	0	0
COMM & DATA	197	89	24	17	3	3	57	4	0	1
ECLSS	250	92	77	29	0	0	0	0	0	52
CREW PROV	39	3	35	1	0	0	0	0	0	0
THROUGHPUT	0	0	0	0	0	0	0	0	0	0
SUBTOTAL	1429	301	264	171	149	136	222	43	44	98
SYS TEST HDWE	1189	251	220	142	124	113	185	36	37	82
INT ASSY, &C/O	161	34	30	19	17	15	25	5	5	11
SYS TEST OPN	587	124	109	70	61	56	91	18	18	40
GR SPT EQMT	468	99	87	56	49	44	73	14	15	32
SYS ENGR & INT	327	69	60	39	34	31	51	10	10	22
PROG MGMT	241	51	45	29	25	23	38	7	7	17
TOTAL	4401	928	814	527	458	419	685	132	137	302
PROG SPT (14%)	616	130	114	74	64	59	96	18	19	42
MGMT & INT (5%)	251	53	46	30	26	24	39	8	8	17
FEE (8%)	421	89	78	50	44	40	66	13	13	29
TOTAL	5690	1200	1053	681	592	541	885	171	177	391

FIG. 3.3.6-2B

ON
OF FOCUSING

COST SUMMARY- DELTA CONCEPT

FIRST UNIT - PROD PHASE

SUBSYSTEM	SUBSYS TOTALS	COST (MILLIONS OF 84 \$\$)								
		C/C	HAB	LAB	IMI	A/L	TRS	OMV	TNL	LOG
STRUCTURE	407	63	114	64	38	34	16	11	9	57
..PRESSURIZED	278	49	96	49	13	13	0	0	9	49
..SECONDARY	44	7	11	6	3	3	8	4	0	3
..DOCK & BERTH	29	3	3	5	8	8	0	0	0	3
..MECH' ISMS	56	4	4	4	14	11	8	8	0	3
THERMAL	88	18	16	31	1	0	21	0	0	1
G N & C	74	8	1	1	33	32	0	0	0	0
..ELECTRONICS	46	2	1	1	25	17	0	0	0	0
..CMG	23	0	0	0	8	15	0	0	0	0
..MAG TORQUERS	6	6	0	0	0	0	0	0	0	0
RCS	2	2	0	0	0	0	0	0	0	0
POWER	71	3	3	3	0	0	60	0	0	2
..SOLAR ARRAY	45	0	0	0	0	0	45	0	0	0
..BATTERIES	0	0	0	0	0	0	0	0	0	0
..COND & REG	11	3	3	3	0	0	0	0	0	2
..FUEL CELL	15	0	0	0	0	0	15	0	0	0
COMM & DATA	91	40	14	12	1	2	18	4	0	1
ECLSS	147	52	48	24	0	0	0	0	0	23
CREW PROV	24	3	19	2	0	0	0	0	0	0
THROUGHPUT	0	0	0	0	0	0	0	0	0	0
SUBTOTAL	905	189	215	137	73	68	114	15	9	85
SYS TEST HDWE	0	0	0	0	0	0	0	0	0	0
INT, ASSY, & C/O	100	21	24	15	8	7	13	2	1	9
SYS TEST OPN	0	0	0	0	0	0	0	0	0	0
GR SPT EQMT	0	0	0	0	0	0	0	0	0	0
SYS ENGR & INT	68	14	16	10	5	5	9	1	1	6
PROG MGMT	84	17	20	13	7	6	11	1	1	8
TOTAL	1156	241	275	175	93	86	146	19	12	108
PROG SPT (14%)	162	34	38	25	13	12	20	3	2	15
MGT & INT (5%)	66	14	16	10	5	5	8	1	1	6
FEE (8%)	111	23	26	17	9	8	14	2	1	10
TOTAL UNIT	1494	311	355	227	121	112	189	24	16	140

FIG. 3.3.6-2C

COST SUMMARY- DELTA CONCEPT

DDTE + FIRST UNIT

SUBSYSTEM	SUBSYS TOTALS	COST (MILLIONS OF 84 \$)								
		C/C	HAB	LAB	IMI	A/L	TRS	OMV	TML	LOG
STRUCTURE	983	132	225	127	116	91	89	50	54	100
..PRESSURIZED	497	72	140	72	43	43	0	0	54	72
..SECONDARY	301	50	76	40	20	20	51	24	0	20
..DOCK & BERTH	50	4	4	10	14	14	0	0	0	4
..MECH' ISMS	135	5	5	5	38	13	38	26	0	4
THERMAL	193	42	29	88	1	0	32	0	0	1
6 M & C	233	19	3	3	101	108	0	0	0	0
..ELECTRONICS	162	11	3	3	80	67	0	0	0	0
..CMS	63	0	0	0	21	42	0	0	0	0
..MAG TORQUERS	8	8	0	0	0	0	0	0	0	0
RCS	11	11	0	0	0	0	0	0	0	0
POWER	166	8	6	6	0	0	142	0	0	4
..SOLAR ARRAY	69	0	0	0	0	0	69	0	0	0
..BATTERIES	0	0	0	0	0	0	0	0	0	0
..COND & REG	25	8	6	6	0	0	0	0	0	4
..FUEL CELL	72	0	0	0	0	0	72	0	0	0
COMM & DATA	289	129	38	28	4	4	74	8	0	3
ECLSS	397	143	125	53	0	0	0	0	0	75
CREW PROV	63	6	54	3	0	0	0	0	0	0
THROUGHPUT	0	0	0	0	0	0	0	0	0	0
SUBTOTAL	2334	490	480	308	222	203	337	58	54	183
SYS TEST HDWE	1189	251	220	142	124	113	185	36	37	82
INT, ASSY, & C/O	262	55	54	35	25	23	38	6	6	20
SYS TEST OPN	587	124	109	70	61	56	91	18	18	40
GR SPT EQMT	468	99	87	56	49	44	73	14	15	32
SYS ENGR & INT	394	83	76	49	39	36	59	11	11	29
PROG MGMT	325	68	64	42	32	29	48	9	8	24
TOTAL	5557	1169	1089	702	551	505	831	151	149	410
PROG SPT (14%)	778	164	152	98	77	71	116	21	21	57.45
MGT & INT (5%)	317	67	62	40	31	29	47	9	8	23.39
FEE (8%)	532	112	104	67	53	48	80	14	14	39.29
TOTAL	7184	1511	1408	908	713	653	1074	195	192	530

FIG. 3.3.6-3

DELTA CONFIGURATION

OF PROGRAM COSTS

COST SUMMARY BY MODULE

QTY	MODULE	FY84\$\$ (IN MILLIONS)			TOTAL
		DDTE	UNIT	PROD	
1	CMD & CNTRL	301	189	189	490
1	HAB MOD	264	215	215	480
2	LAR MOD	171	137	275	446
2	I/F MOD	149	73	146	295
2	A/L MOD	136	68	135	271
3	TRUSS	222	114	343	565
1	HANGAR	43	15	15	59
1	TUNNEL	44	9	9	54
1	LOG MOD	98	85	85	183
HDM SUBTOTAL		1429	905	1411	2334
SYS TEST HDM		1189	0	0	1189
INT, ASSY, C/O		161	100	156	318
SYS TEST OPN		587	0	0	587
GR SPT EQMT		468	0	0	468
SYS ENG & INT		327	68	105	432
PROG MGMT		241	84	130	371
SYS TOTAL		4401	115	1803	6204
PROG SPT		616	162	252	869
MGT & INT		251	66	103	354
FEE		421	111	173	594
PROG TOTAL		5690	1494	2331	8021

the totals found in figure 3.3.6-2 for DDT&E and Production (First Unit). The third cost column is the total production costs taking into account the quantities of each module or element. The final column is the total of the DDT&E and Production costs and is therefore, the total of the Space Station at IOC.

3.4 "T" Configuration Evaluation

3.4.1 User Accommodation Evaluation

3.4.1.1 Viewing

The "T" Space Station configuration will provide for constant earth viewing at a 28.5° inclination. It is like the BB configuration in that the pressurized lab will always be earth oriented. It is like the delta truss configuration in locating the unpressurized sensors for solar and stellar viewing along the solar cell truss. The viewing frequency for stellar is again limited for a specific target. However, it is possible to accommodate simultaneous earth, solar, and stellar viewing with this configuration.

3.4.1.2 Power

The power supplied to the user at IOC will be 60 KW continuous and at growth it will be 120 KW continuous.

3.4.1.3 Pressurized Volume

The pressurized volume at IOC provided to the user is two 22 foot modules. For growth, a total of four 22 foot modules are provided with one 44 foot module. The 44 foot module offers facility versatility in the growth phase and the two 22 foot modules offer flexibility at IOC. However, this is an issue; see Section 5.0.

3.4.1.4 Crew Time

A considerable amount of the crew's time has been allocated to the user as shown in sections 3.2.4, 3.3.4, and 3.4.4, each section pertaining to the building block configuration, delta truss configuration, and "T" configuration respectively.

3.4.1.5 External Attachments

A pallet attachment for the user is possible with this configuration.

3.4.1.6 Microgravity

The acceleration level at the modules that require low gravitational levels are assumed to be 10^{-4} g nominal. However, the effect of the modules distance from the station's c.g. has not been determined and needs to be considered for each configuration.

3.4.2 Crew Accommodations Evaluation

Due to the amount of equipment and the arrangement of the floor and ceiling, the C/C module only has the capability of having windows in one plane. It would be desirable to have windows capable of viewing all directions. Crew accommodations in the module are the WCS, a minimal galley, stored food for eight people for 22 days and a hygiene station. The accommodations are adequate.

If the manipulator is controlled from this module, the limited visibility will require additional windows or video equipment and perhaps at times, EVA crewperson to guide the manipulator.

The habitability module provides sleeping quarters, personal hygiene, medical facilities, and a galley/wardroom. The private sleeping quarter volume is adequate for sleeping, dressing, video training, and entertainment, grooming, and associated activities. It is generally preferable to have the sleeping

quarters located away from noisy equipment which would disturb a sleeping crew person. The habitability module does not entirely succeed in doing this, for adjacent to the sleeping quarters is the Personal Hygiene and Medical Facility. The Personal Hygiene area contains two combinations shower/urinal/handwash facilities and a Waste Control System (WCS). The Medical Facility contains limited medical equipment and supplies and the physical conditioning equipment. To make their location in the habitability module acceptable, the WCS and health maintenance equipment noise levels must be sufficiently low to avoid disturbing a sleeping crewperson or special acoustical isolation must be provided. The Personal Hygiene Facility coupled with a WCS in the Command and Control Module is adequate for eight crewpersons. The galley and wardroom provide facilities for use by eight crewpersons simultaneously which is adequate. The wardroom area should provide a capability for group training or entertainment.

For growth, a second similar habitability module is added to the station and the medical/physical conditioning equipment is moved to the Life Sciences Lab. The second habitability module is adequate for the increase in crew.

The habitability module is designed to permit unimpeded passage through the module. The module maintains a consistent heads-up orientation which is desirable. The floor and ceiling are offset from the module walls to allow utility equipment location. This combination renders it difficult to locate windows in these areas and consequently there are none. (It would be desirable to have windows encircling the module.)

The big "T" size and configuration has the following disadvantages:

- o About one-third of the view from any module is blocked by structure/solar arrays/other module. It is desirable to be able to view in all directions from a module.

o An EVA crewperson to reach the critical systems equipment on the "top of the T" must traverse considerable distance. This is not a decisive factor; however, it does add to the work, time, and complexity of the EVA. The existing manipulator system is only 50 feet in length. To reach all areas of the station will require:

- o The development of a new manipulator
- o Moveable manipulator
- o Numerous manipulators

3.4.3.1 Assembly and Growth Evaluation

A preliminary launch-by-launch buildup sequence has been developed and is summarized in figure 3.4.3.1-1. This sequence is based on Orbiter payload bay packaging that is plausible but optimistic. It is assumed that an Orbiter docking module is carried on all flights. Where possible, all elements are installed initially in their final locations. Exceptions are indicated in figure 3.4.3.1-1 by an arrow from the flight that launches the element to the flight on which it is moved to its final location. Completion of IOC and growth capabilities is denoted by heavy vertical lines. Figure 3.4.3.1-2 illustrates the assumed packaging in the payload bay for each launch required for IOC.

3.4.3.1.1 User Accommodation: Assembly and Growth

The "T" provides substantial versatility in accommodations for users. The truss has large non-dedicated areas that are useable for most unpressurized payloads. It would also be possible to place additional pressurized modules along the sides of the truss, although radiators would have to be relocated. The order in which facilities are added is also relatively unconstrained after the first few launches.

BUILDUP SEQUENCE

ORIGINAL
OF POOR

Configuration Big "T"

Date 12/1/83

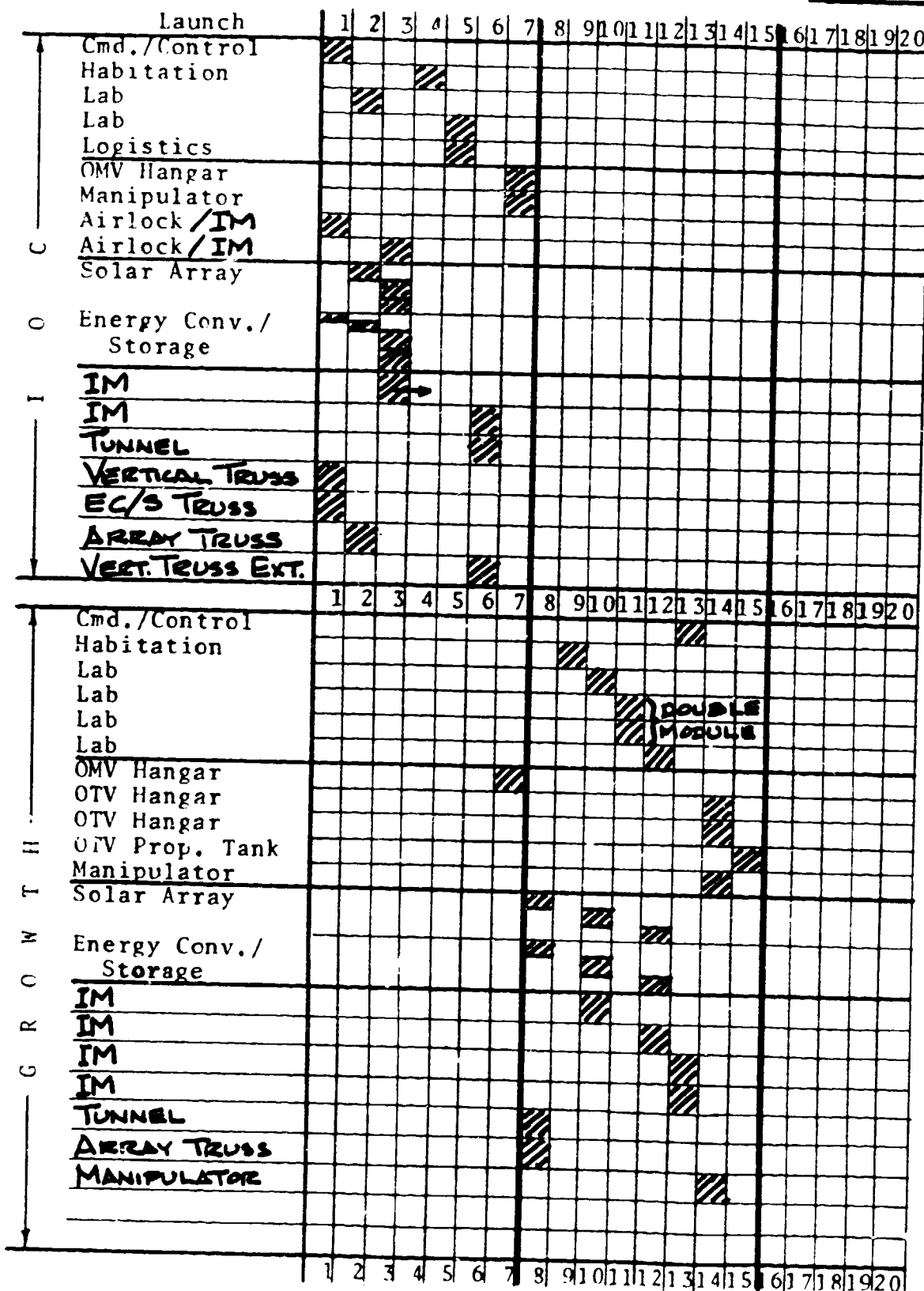


Figure 3.4.3.1-1

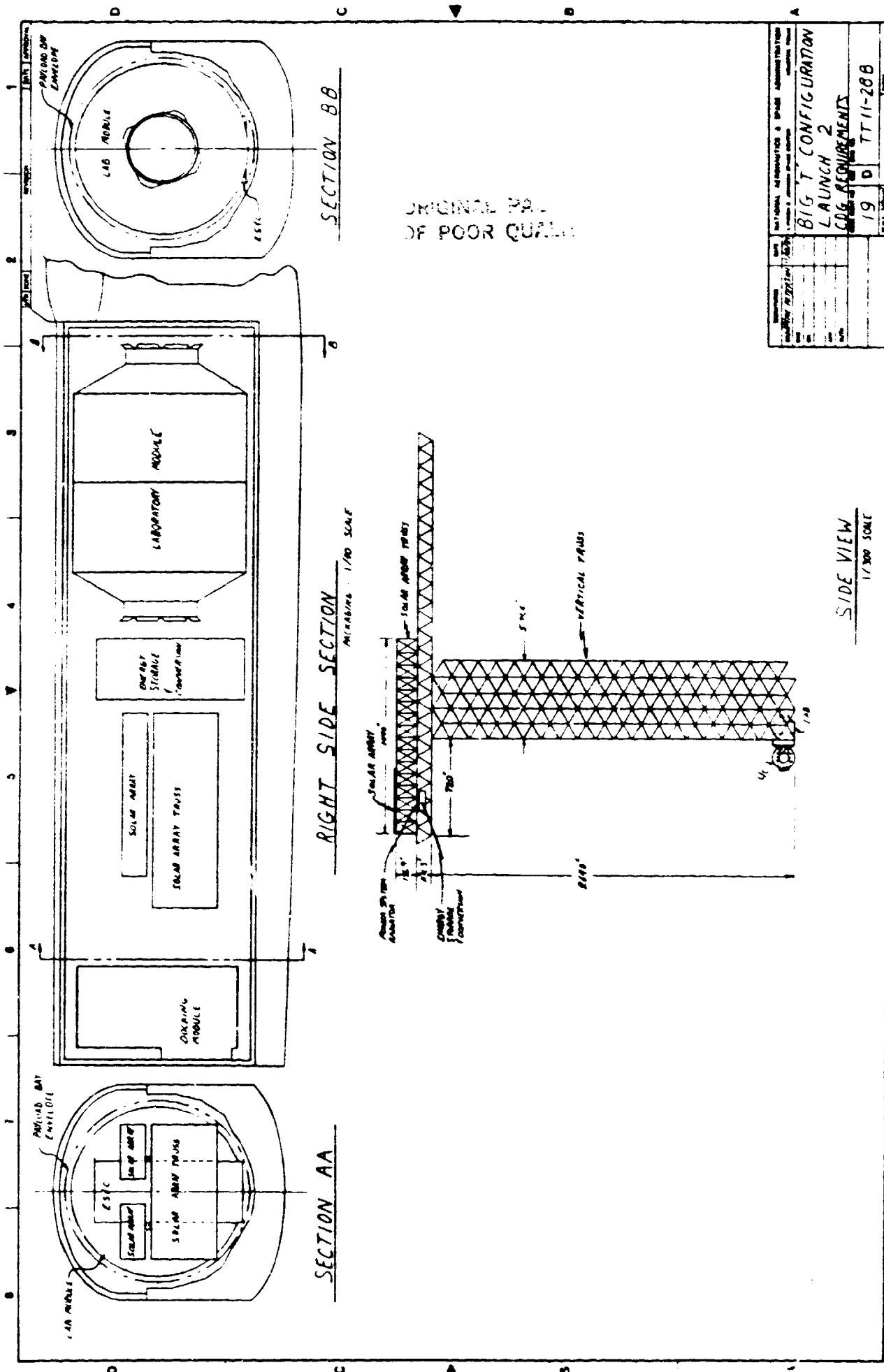


Figure 3.4.3.1-2b



Figure 3.4.3.1-2e

3.4.3.1.2 Systems Engineering: Assembly and Growth

It is assumed that work requiring a low-gravity environment will be suspended during any station assembly operations, and therefore that this is not a discriminator. The principal inertia axes will shift when an Orbiter is berthed but not enough to have a major impact on power input.

Transition efficiency is fairly good. One IM must be relocated in the reference buildup scheme.

The energy storage unit on the first launch contains cryogenic oxygen and hydrogen to supply minimal power until a solar array is launched on the second flight, venting or storing the excess water produced. It subsequently functions as a regenerative fuel cell with gaseous reactants. Subsequent energy storage units are launched with gaseous reactants. There are no elements in the early phase that are discarded in later stages.

Assembly will require the full capability of the Orbiter RMS. A second RMS or a handling and positioning aid will be needed in some steps. Note that the RMS reach analysis in section 3.4.4.2 assumes a large manipulator on the station at an early point in the buildup in lieu of a handling and positioning aid. Substantial EVA will probably be necessary, primarily for joining of truss sections and installation of equipment. Deploying a truss section and joining it to an existing truss appears possible but difficult.

Removal of a module does not affect the structural characteristics of the station. If the pressure loads between modules are carried through the truss, removal is a simple process of disconnecting internal and external umbilicals, closing hatches, and depressurizing and retracting the intermodule connectors. If the loads are carried directly between modules, the task may be more difficult depending on the design of the connectors.

Two Orbiter berthing ports are available at IOC and four in the growth configuration. Twenty-four other ports are available for logistics modules and other temporary payloads, since each IM has six ports.

3.4.3.1.3 Programmatics: Assembly and Growth

The reference buildup scenario achieves IOC in seven launches. Sufficient critical system redundancy for permanent manning is reached in four launches. At this point, crew size is limited by the lack of a logistics module but an LM provides facilities for useful work.

Full growth capability is reached in 15 launches. Efficient hangar design and packaging could reduce this by one flight so that full capability might be achieved in 14 flights.

3.4.3.1.4 Safety: Assembly and Growth

The OTV propellant storage facility is located about 65 feet from the inhabited modules although an alternative arrangement places it about 40 feet away. A separation of up to 150 feet can be provided, if desired, with minimal impact on station function.

Isolation of a hazardous condition, such as a spill of a toxic substance, can be done with little difficulty. Since there are two routes to each module, any one can be isolated without significant disruption of other activities.

3.4.3.2 Structural Dynamics and Control Evaluation

The "T" configuration is designed to fly in the LVLH mode (see figure 3.4.3.2-1). In that flight mode the "T" is pitched in the orbit plane to achieve a TEA condition. The CMG's control the resulting cyclic torque disturbances. The TEA flight condition is achieved by flying the "T" at different pitch attitudes and iterating to a resultant equilibrium condition.



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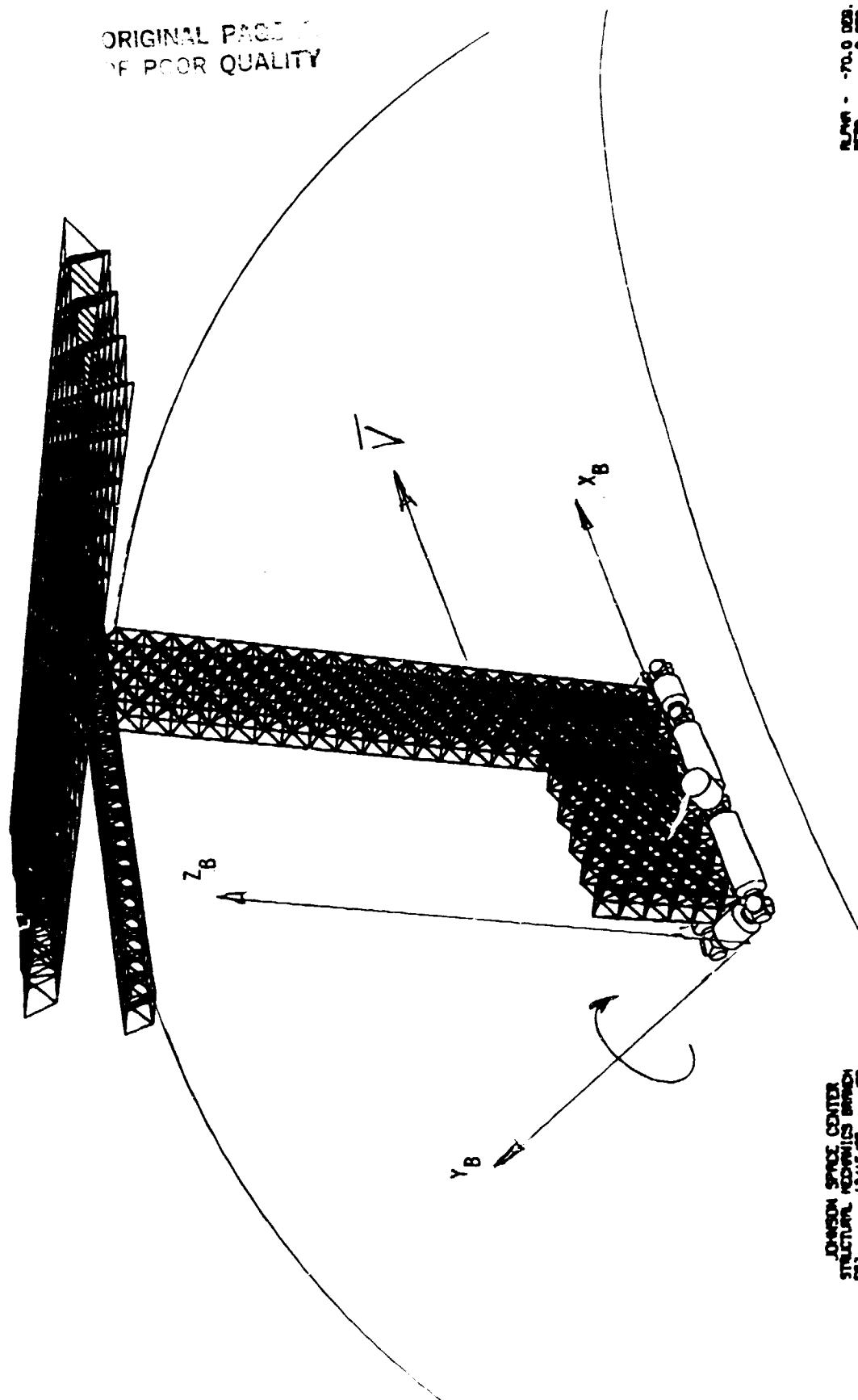


Figure 3.4.3.2-1 "T" Flight Orientation

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3.4.3.2.2 Orbit Disturbances

Operation in low earth orbit (270 NM) provides exposure to significant gravity gradient torque disturbances. These are on the order of 50-foot pounds. While relatively insignificant from a controllability point of view, the extreme time span of the Space Station mission makes these significant drivers for "cost-of-ownership," unless steps are taken to minimize their influence.

3.4.3.2.3 Aerodynamic Torque Disturbance

In addition of gravity gradient torques, the aerodynamic torques can produce secular momentum accumulation. However, the asymmetric effect of the diurnal atmosphere variation has been neglected for this analysis. In the earth fixed mode, the large areas of the solar arrays are never directly exposed to the free molecular flow particle velocity for the "T"; hence, only effects of the modules and

truss edges are involved for these configurations.

3.4.3.2.4 Mass Properties Management

Mass properties management scheme must be employed in the Space Station design in order to enhance the flight performance. The mass properties should be adjusted so that at the TEA condition the geometric axis aligns with the LVLH; this will reduce the overall drag forces. The mass properties for the "T" are shown below:

BIG "T"

	IOC	Growth	
IXXP	7.04 E 7	10.5 E 7	slugs-ft ²
IYYP	8.2 E 7	14.2 E 7	slugs-ft ²
IZZP	2.4 E 7	5.5 E 7	slugs-ft ²
θ_x^*	-1.0°	.87°	
θ_y^*	-5.7°	-8°	
θ_z^*	0°	.57°	
R_x	33.1	79.1	ft
R_y	03.75	-1.29	ft
R_z	45.8	42.3	ft
Wgt	308.K	702.5K	

* Euler angels; rotate from geometric axes to principal axes with rotation order θ_x , θ_y , and θ_z . R_x , R_y , R_z center of mass center IXXP, IYYP, IZZP, principal inertias.

3.4.3.2.5 Momentum Storage Requirements

Momentum storage requirements are based upon the peak cyclic momentum variations and the attitude control system philosophy regarding the amount of reliance on the CMG's for attitude maneuvers and absorption of large impulsive disturbances (i.e., mix between CMG torque impulse and RCS torque impulse). Peak cyclic momentum storage for the "T" configuration due to aerodynamic torque and gravity gradient are presented below. Due to the time available for this study, the momentum storage equipment was sized only for the nominal flight conditions involving attitude hold.

Flight Mode	IOC	Growth
Earth Fixed	4,500 Ft-lbs	6,000 Ft-lbs

3.4.3.2.6 Orbital Maintenance Impulse Requirements

Orbital maintenance impulse was determined using the NASA neutral atmosphere (SP-8021) density at 270 NM and average aerodynamic properties to compute the drag impulse. The NASA neutral atmosphere is considered to be the worst long-term atmosphere applicable to a 90-day resupply cycle. Short term maximum conditions should be used for RCS engine magnitude sizing.

The disturbance simulation used a dynamic pressure of $.99905E-6$ lb/ft².

Summary results for the three configurations are shown below:

DRAG IMPULSE PER ORBIT (LB-SEC/ORBIT)		
Flight Mode	IOC	Growth
Earth Fixed	113	95

Using the data shown above, worst case resupply propellant for altitude maintenance was calculated and is presented below. Assuming that the orbit is not allowed to deviate from 270 NM.

90-DAY RESUPPLY PROPELLANT FOR ALTITUDE MAINTENANCE FOR 270 NM

LBS - Normalized to: ISP = 220 sec.

Flight Mode	IOC	Growth
Earth Fixed	700	590

3.4.3.2.7 RCS Firing Frequency

Detailed flight dynamic simulations show that the "T" configuration can be trimmed so that there is no secular torque momentum accumulation per orbit. Thus, no RCS firing are required for CMG desaturation. The "T" configuration can achieve a minimum RCS attitude maintenance firing frequency of once every

90-days chosen to coincide with STS resupply. This will be particularly attractive to long term low "g" scientific experiments and manufacturing processes. Attitude loss will be less than three miles in 90-days.

3.4.3.2.8 Results of On-Orbit Flight Dynamics for the "T" IOC

The results of the on-orbit flight dynamics are shown in figures 3.4.3.2-2 through 3.4.3.2-4. The torque impulse history curves shown in figure 3.4.3.2-2 show that equilibrium was not quite reached. (ITY = 6,600 ft-lb-sec/Orbit). The cyclic momentum storage requirement is 4,500 ft-lb-sec will not change significantly if further iterations are made. The aerodynamic drag impulse history shown in figure 3.4.3.2-3 is 113 lb-sec/orbit.

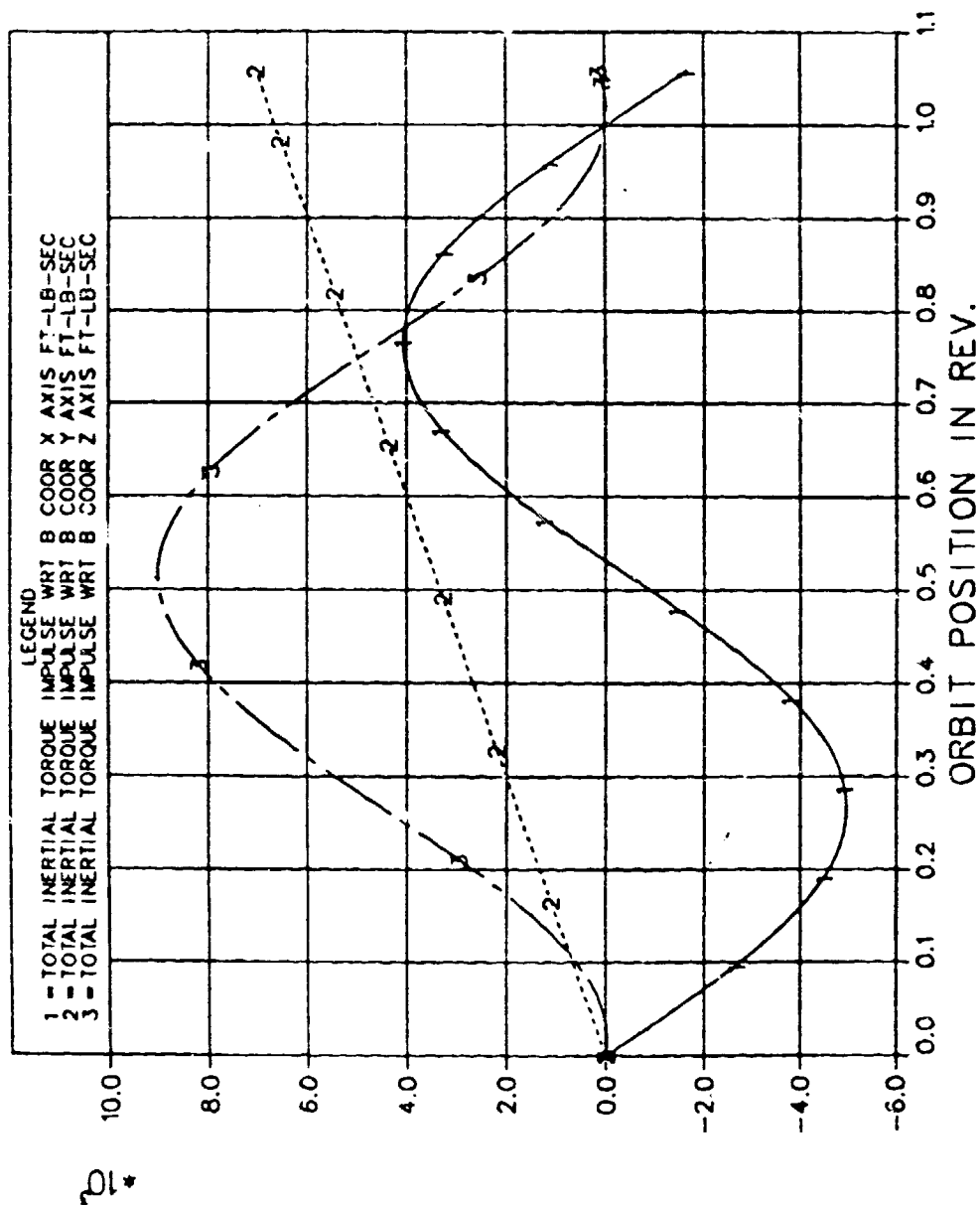
3.4.3.2.9 Results of On-Orbit Flight Dynamics for the "T" Growth

The results of the on-orbit flight dynamics are shown in figures 3.4.3.2-5 through 3.4.3.2-6. The torque impulse history curves in figure 3.4.3.2-6 show that equilibrium was not quite reached (ITY = 2,000 ft-lb-sec/orbit). The cyclic momentum storage requirement is 6,000 ft-lb-sec and will not change significantly, in further iterations, the aerodynamic drag impulse history shown in figure 3.4.3.2-5 is 95.0 lb-sec/orbit. Figure 3.4.3.2-6 shows the torque impulse history imbalance if the "T" is flown with its geometric axes aligned with the LVLH.

3.4.3.2.10 Structural Dynamics and Control

A NASTRAN finite element model of the big "T" (figure 3.4.3.2-7) was created to aid in the structural dynamic analysis. This configuration utilizes the structural truss concept. Deployable or erectable trusses have many attractive features for the Space Station structural subsystem. The section depths of 8-10 feet enhance the structural bending stiffness which results in higher overall system model frequencies. The Streamlined "T" and the Delta

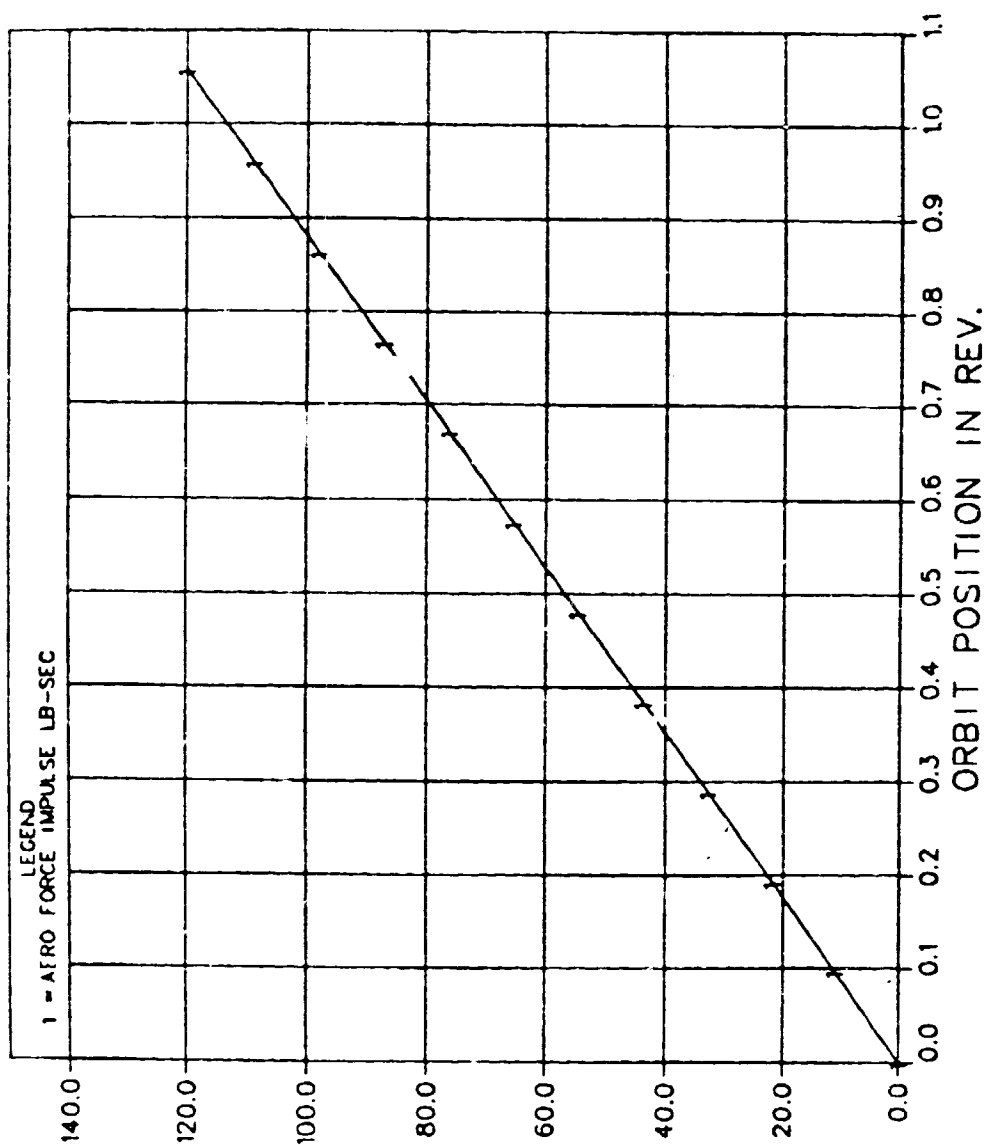
BIG-T, INCL=0.0, PITCH=7, ARRAY=0, ORB RATE YC AXES



ES4 Structures Dec 7, 1983

Figure 3.4.2.2-2 "T"-LOC Momentum Accumulation Time History

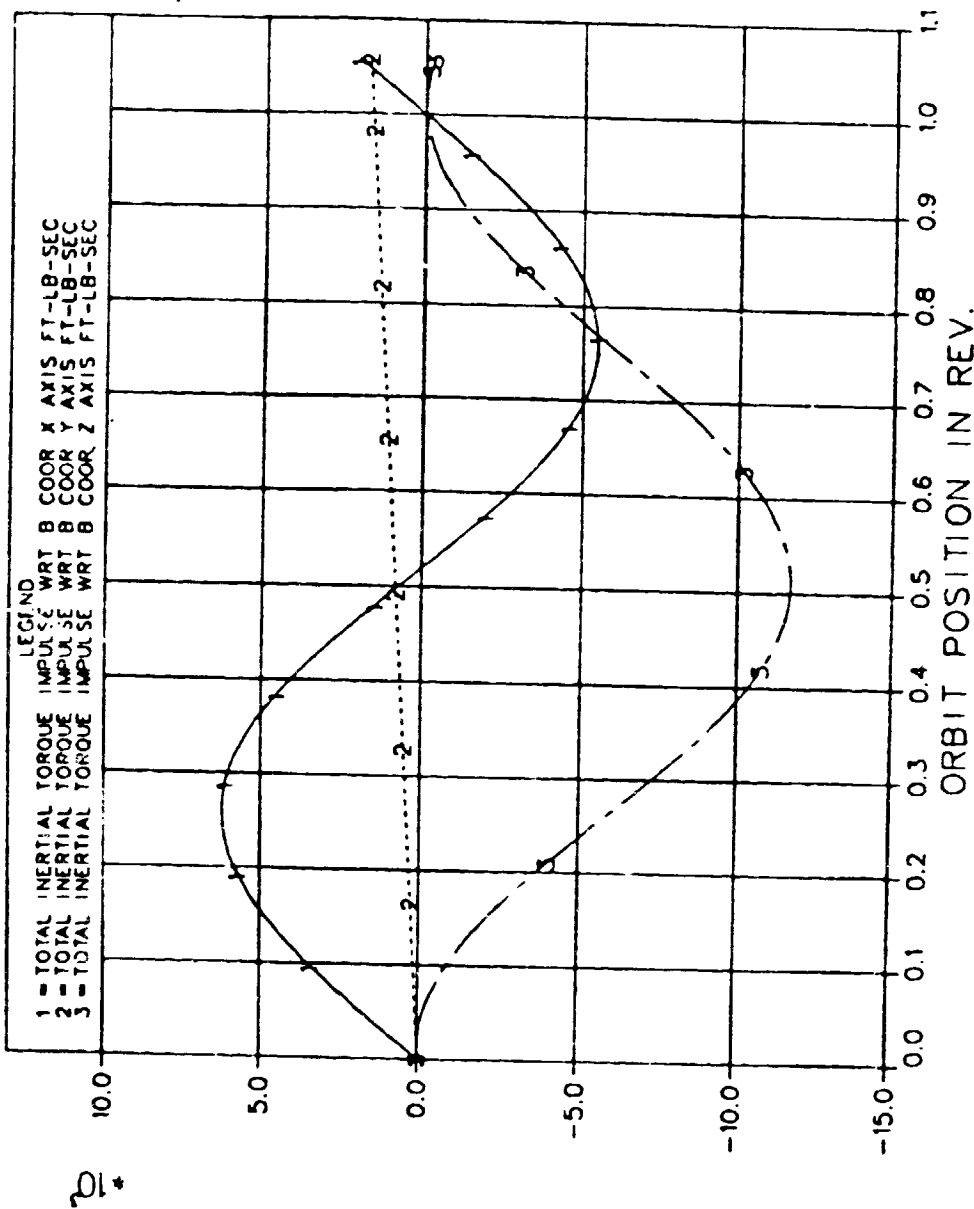
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Figure 3.4.3.2-3 "T"-IOC Aerodynamic Drag Impulse Time History

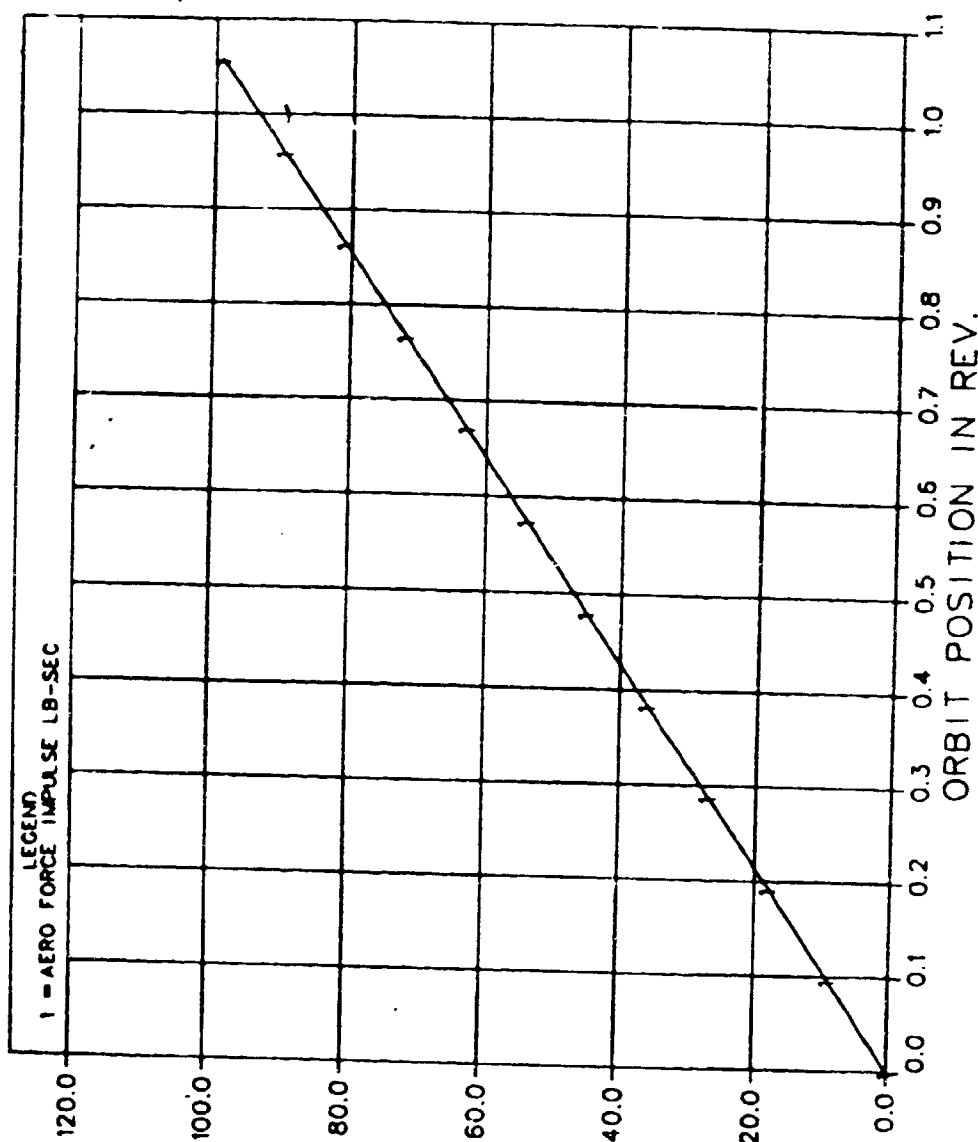
BIG-T, INCL=0.0, SUN=-52, ARRAY=0, ORB RATE YC AXES



ES4 Structures Dec 5, 1983

Figure 3.4.2.2-4 "T"-GROWTH Momentum Accumulation Time History

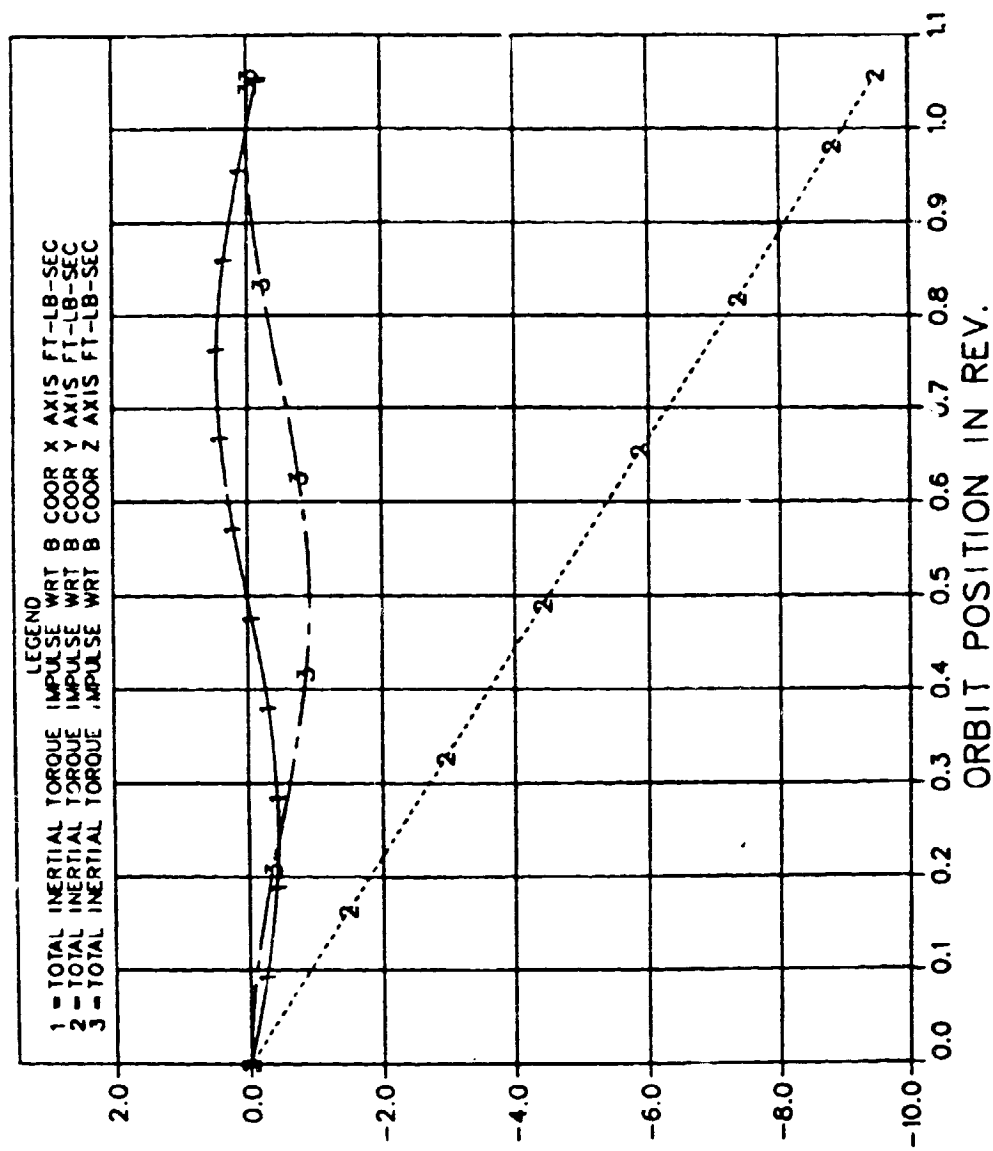
BIG-T, INCL=0.0, SUN=-52, ARRAY=0, ORB RATE YC AXES



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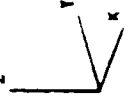
Figure 3.4.3.2-5 "T"-GROWTH Aerodynamic Drag Impulse Time History

BIG-T, INCL=0.0, SUN=-52, ARRAY=0.0,0.0 RATE YC AXES



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Figure 3.4.2.2-6 "T"-GROWTH Momentum Accumulation Time History



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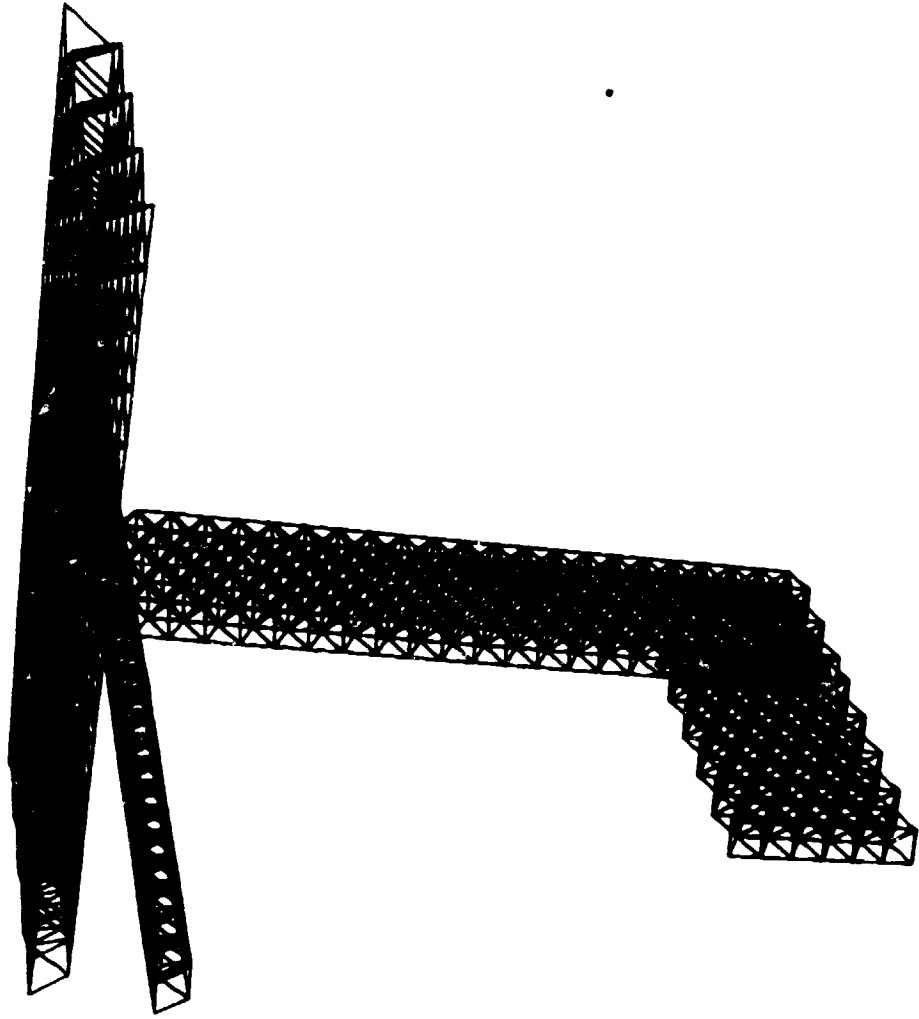


Figure 3.4.3.2-7 Finite Element Model of Streamlined "T"

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concepts both utilized this technology to achieve a significant improvement in natural frequency over the BBC. The fundamental mode for the Streamlined "T" is array bending at 0.45 Hz. The dynamic behavior of this system is penalized by the large amount of non-structural mass associated with the over-sized solar array. The additional geometric dimensions and increased distributed array mass caused by the inefficient array pointing subtract from the structural advantages of the truss. In addition, the structural details of the hinged interface have not been given adequate design attention to speculate on the compliance of this system. In this analysis, the hinged interface was locked so that analytical attention could be focused on the array size trade. A hinged interface between the module support truss and the array support truss may contribute to an additional low frequency pendulum mode where the truss systems move relative to each other. This mode would be a candidate for active control system damping. Module placement for this concept is an improvement on the BB design by allowing multiple attachment opportunities along the length of the modules.

For the Streamlined "T" configuration, a single axis control system was developed that utilized the maximum rotational inertia for the vehicle dynamics model. Second order models were used for the CMG and angular rate dynamics. The resulting closed loop control system exhibited nearly critically damped CMG/rate poles near the open loop values. Controller bandpass was determined from the frequency response analysis (Bode plot). The Streamlined "T" showed the slowest time response which is attributable to the rotational inertia of this system. In frequency this translates to a smaller bandpass; in this case, 0.28 Hz. Comparing this value with the structural analysis that indicates a first array bending mode at 0.45 Hz, a marginal separation between the flex spectrum and the controller bandpass is observed.

A rigid body type control system should be suitable for this configuration, although some filtering may be required due to the close proximity of the bending frequencies to the bandpass frequency.

The structural dynamics of the streamline "T" during intermediate buildup stages was not analyzed at this time. The various stages will produce significantly different results from the analysis of the completed versions.

This concept, with its large truss areas, will change modal frequencies and shapes during construction to the IOC configuration. However, once established, the growth of the "T" by the addition of more modules will not excessively complicate the changes in vehicle dynamics.

3.4.3.2.11 Summary of On-Orbit Flight Dynamics

The flight dynamics of the configurations have been studied in detail for the earth fixed (LVLH) attitude hold. Using mass properties management to control the system inertias, the TEA trim adjustments the momentum accumulation can be reduced to zero. Propellant resupply weight of up to 700 lbs. for orbit maintenance does not seem to be a critical item.

The "T" configuration because of the use of the deployable truss to support the solar array, causes a higher frequency of the first array bending mode. Increased in the size of the solar array for growth versions will lower this frequency.

3.4.3.3 Communications Evaluation

The communication subsystem consists of hardware required to establish communication links between the Space Station and various vehicles. Antenna requirements for the subsystem are essentially the sum total of those requirements developed by considering each link separately. In this

subsection, we will develop antenna specifications for the big "T" configuration by sequentially describing each operating link. Information on RF coverage, number of required antennas, type, makeup and size of these antennas, and their estimated locations on the Space Station structure are given. Also, the ease of procurement or development of such antennas is discussed. The antenna design selected for this configuration to meet each required link coverage was based on studies that have been completed to date. Further study and evaluation could dictate alternative options that might be more advantageous based on numbers of antennas required and development risks. A summary of the antenna requirements for the big "T" configuration is given in table 3.4.3.3-1. The antenna locations for the IOC and growth big "T" configuration is shown in figure 2.4-1 and 2.4-2.

a. Space Shuttle Orbiter (SSO) Link - This is an S-band link that supports two-way communication between the Space Station and the Space Shuttle Orbiter. Only one SSO is supported in IOC and two SSO's are supported in the growth version. The coverage required is limited to the hemisphere below the Space Station and extends to about 50 km in most directions except in a small sector directly behind the Space Station where it extends all the way to 2000 km.

The link is to be served with one medium gain (30 dB) phased array antenna made up of about 500 elements and measuring about 10 feet in diameter. The optimum location for such an antenna is somewhere on the bottom portion of the Space Station in such a way that the lower hemisphere is visible and unobstructed by Space Station structure elements. On this configuration, the antenna is mounted to the underside of the solar panel support truss.

Table 3.4.3.3-1

Antenna Requirements for the Big "T" Configuration

<u>Communication Link</u>	<u>Antenna Type</u>	<u>Number of Antennas</u>	
		<u>IOC</u>	<u>Growth</u>
Space Shuttle Orbiter	S-band medium gain phased array	1	1
Multiple access link to EMU, FF, OMV Vehicles	K-band high gain multibeam phased array	2	2
	K-band medium gain multibeam phased array	2	2
Tracking and Data Relay Satellite	S/Ku-band dual feed dual frequency steerable parabolic reflector	1	1
Global Positioning System	L-band widebeam omni	1	1
Television	K-band high gain single beam phased array	4	12
Orbital Transfer Vehicle	K-band medium gain multibeam phased array	0	2
Space Shuttle Orbiter Rendezvous Radar	Omni directional	2	2
Rendezvous	Parabolic Reflector monopulse feed	2	2
Multiple Tracking	High gain phased array	0	2
	Medium gain phased array	0	2

Procurement of this antenna represents routine design and development effort if the array is passive (electronics separate from antenna elements). However, some risk is introduced in the development if the array is active with monolithic design (electronics combined with the antenna elements in one package).

b. Multiple Access (MA) Link - This is a K-band link that supports two-way communication between the Space Station and the EMU, FF, and OMV vehicles. The coverage is divided into two parts. The far range (to 2,000 km) coverage is a 20° conical sector centered about the velocity vector in the forward and aft directions. For short range, the coverage is 4 pi - steroidal to about 400 km.

Two high gain (41 dB) multibeam phased array antennas made up of about 16,000 elements and measuring about 28 inches in diameter each will serve the far range sectors. These antennas must be mounted on the Space Station in such a way that their broadside direction is along the flight path. On this configuration, they are located on the section of the truss protruding on either side of the solar panel.

The above specification for the two high gain antennas assured an operating frequency in the Ka-band at about 28 GHz. There will be medium amount of risk associated with the development of such a large array antenna (16,000 elements) in the passive mode. The risk becomes high if the array design is active and monolithic. The design difficulty can be reduced considerably by moving to a lower frequency like Ku-band where an array size of about 1,000 elements will be sufficient due to lower antenna gain (30 dB) and higher antenna efficiency.

Generally, two more antennas are needed to complete the spherical coverage required for short range. These two antennas are medium gain (27 dB

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at Ka-band) multibeam phased arrays where each is comprised of 640 elements and measures about six inches in diameter. Their placement on the Space Station is designed so that one will view the bulk of the upper hemisphere and the other will view the bulk of the lower hemisphere. They are located one on the topside of the solar panel truss and the other on the underside of the leftmost habitat module.

Procurement of the above two antennas represents routine development effort if the array is passive and minimal risk if the array is active and monolithic irrespective of whether the design frequency is in the Ka or Ku bands.

c. Tracking and Data Relay Satellite (TDRS) link - This is a dual S/Ku-band link that supports two-way communication between the Space Station and the TDRS satellite. The coverage required is hemispherical in the elevation plane and forms an 80° sector in the azimuth plane.

The link is to be served with a dual-feed, dual-frequency mechanically steerable parabolic reflector of nine feet diameter. This antenna must be located on the topside of the Space Station in such a way that the upper hemisphere is visible. On this configuration, it is located on the topside of the truss section protruding next to the solar panel.

Procurement of this antenna is subject to a medium level of risk arising from the adaptation of the two feed systems to the mechanically steerable parabolic reflector.

d. TV Links to FF's and OMV's - These are independent Ku-band links relaying digital TV signals from the FF's and OMV's back to the Space Station. Two links are needed in the IOC stage increasing to six links in the growth stage. The coverage on each link will be a 20° cone out to 2,000 km for far range coverage and a hemisphere below the station extending 50 km.

Each link can best be served by high gain conformal phased arrays to obtain a spherical coverage with minimum number of antennas. Each array will have a diameter of about four feet. On this configuration, two arrays are required per link where one is located on the top of the solar panel truss and the other located on the bottom of either the habitat module (IOC) or the lab modules (growth).

The antenna arrays for the TV links represent high risk development items due to the large number of elements that would be involved in the design.

e. Orbital Transfer Vehicle (OTV) Link - This is a K-band link supporting two-way communication with the OTV vehicle in the growth configuration only. The coverage is a full sphere with a maximum radius of 100 km.

The link can be served by a pair of medium gain phased array antennas each covering one hemisphere. The size of each array is 400 elements at Ka-band frequency and measures about five inches in diameter. The placement of these antennas on the Space Station is as follows: one antenna is located on top of the solar panel truss and the other on the underside of the leftmost habitat module.

The development of the array pair presents no risk if the array is passive. Minimum risk results if the array is active.

f. Tracking Links

Four links will be used to provide Space Station position and attitude information, and to provide relative position and velocity information on other Space Colony vehicles and objects within specified volumes of concern. The Global Positioning System (GPS) Satellite Constellation Link is an L-band

receive-only navigation and tracking link. The Space Station GPS antenna must be able to receive code tracking information from a group of four satellites simultaneously. The antenna coverage consists of a 160° cone centered about the Space Station local vertical.

The link would be satisfactorily served by a low gain omnidirectional antenna. This antenna must be mounted on the Space Station in such a way that most of the upper hemisphere is clearly visible. On this configuration, it is mounted on the left solar panel boom.

Procurement of such an antenna is routine, and there is no development risk involved.

A Shuttle Rendezvous Radar link will be completed by a transponder onboard the Space Station. Two transponders and two omnidirectional antennas will be used for this link.

Rendezvous radar links will be used to maintain continuous position and velocity data on vehicles that are approaching the Space Station during the implementation of flight plans which involve docking. Similar position and velocity data will be provided for vehicles that are departing, and are within a specified range of concern. Two antennas, directed fore and aft along the velocity vector, will be used for this function; each antenna is expected to be approximately three feet in diameter.

Multiple vehicle tracking will be accomplished by Search and Track Radars which will maintain updated position information on vehicles at distances as great as 2,000 km. A minimum of five antennas will be used for this purpose, to provide coverage of the fore and aft directions along the velocity vector. A maximum of four antennas will be used to provide complete coverage of a specified volume around the Space Station.

3.4.3.4 Elements/Utilities Interface and Mechanisms Evaluation

3.4.3.4.1 General

The "T" configuration is made up of two large truss surfaces which comprise the basic structure to which other elements, including modules, are attached. The standard berthing interface is used for joining module-to-module, though alternate schemes for routing of some utilities outside the berthing interface offer some advantages. With regard to mechanisms, the rotary joint between the array truss and the vertical truss is a dominant feature, particularly in considering assembly.

As for the delta truss configuration, much of the mechanical systems and interface study effort has focused on assembly of major station elements and on concepts for utilities wiring and plumbing. A major objective is to develop concepts which are compatible with manipulator operations and minimize EVA requirements. In some cases, more detailed design activity will be required to fully establish practical levels of manipulator versus EVA operations. For example, concepts for placement of station electrical wiring using the manipulator appear practical, but limited use of EVA for mating of connectors may avert the need for development of sophisticated mechanisms for that limited purpose. There is a need for more specific trade studies of EVA versus manipulator activities as well as continued evaluation of manipulator capability and complexity of manipulator operations versus capability of assembly mechanisms.

3.4.3.4.2 Berthing Mechanism

Berthing involves use of a manipulator to achieve final closure of two spacecraft or assembly elements, thereby insuring relatively small misalignments and contact velocities. Contact energy attenuation requirements

are low and alignment guides are shorter than would be required for docking operations. The berthing interface comprises alignment guides, structural latches, a telescoping pressure tunnel, retract/extend actuators, utilities interconnect provisions and supporting structure (see figure 3.4.3.4-1). Four alignment guides are incorporated to provide 90° indexing for station elements. Guide length of 5.75" will accommodate expected misalignments for berthing operations. The manipulator, aided by the alignment guides and other sensors as required, brings the interfaces within the envelope of the combined capture/structural latches. Operation of these eight latches, located on the alignment guides, completes the structural mating of the interface. The structural latches are sized to carry the full pressure load and all dynamically induced loads across the interface. Within the 15" length of the berthing mechanism, a 6" stroke of the mating interface will be provided by three pairs of electromechanical actuators. After structural mating is accomplished, these actuators will be fully extended.

The telescoping pressure tunnel, shown in figure 3.4.3.4-2, is extended by independent small electromechanical actuators. The tunnel concept incorporates redundant pressure seals and a complete set of tunnel elements may be extended from either side of the interface.

Truss mounting of the modules may greatly modify the requirements for the berthing interface. If modules can be berthed first to the truss attachment structure, the module to module interface can be simplified. Further, the truss attachment may reduce the loads across the berthing interface, thereby reducing structural requirements. These effects could not be evaluated in sufficient depth to warrant changing the baseline berthing mechanism at this time.

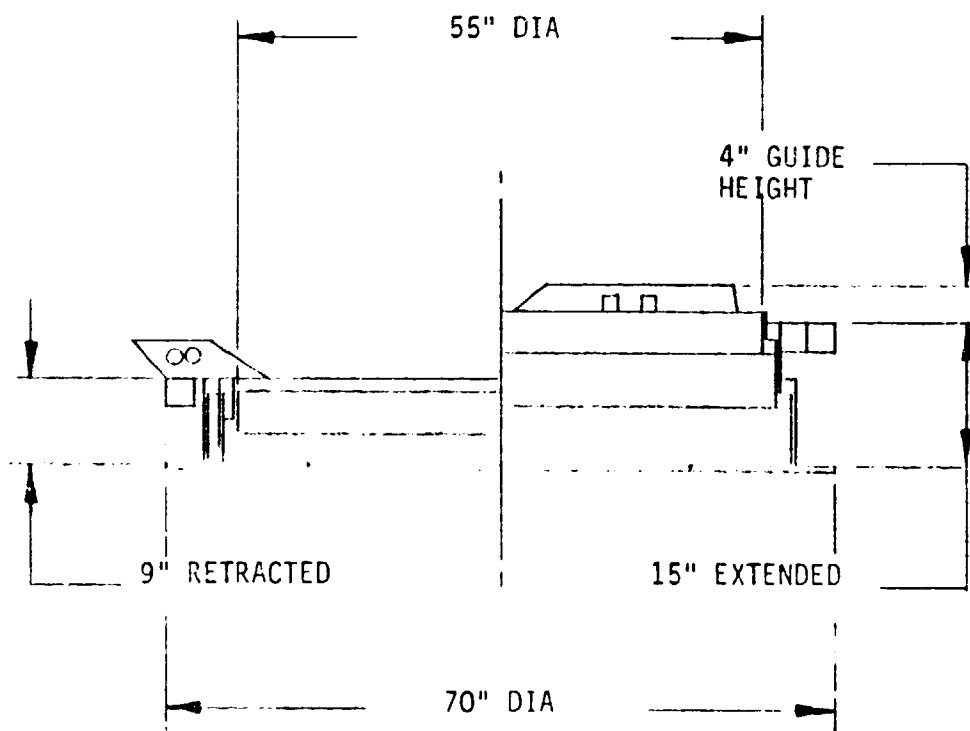
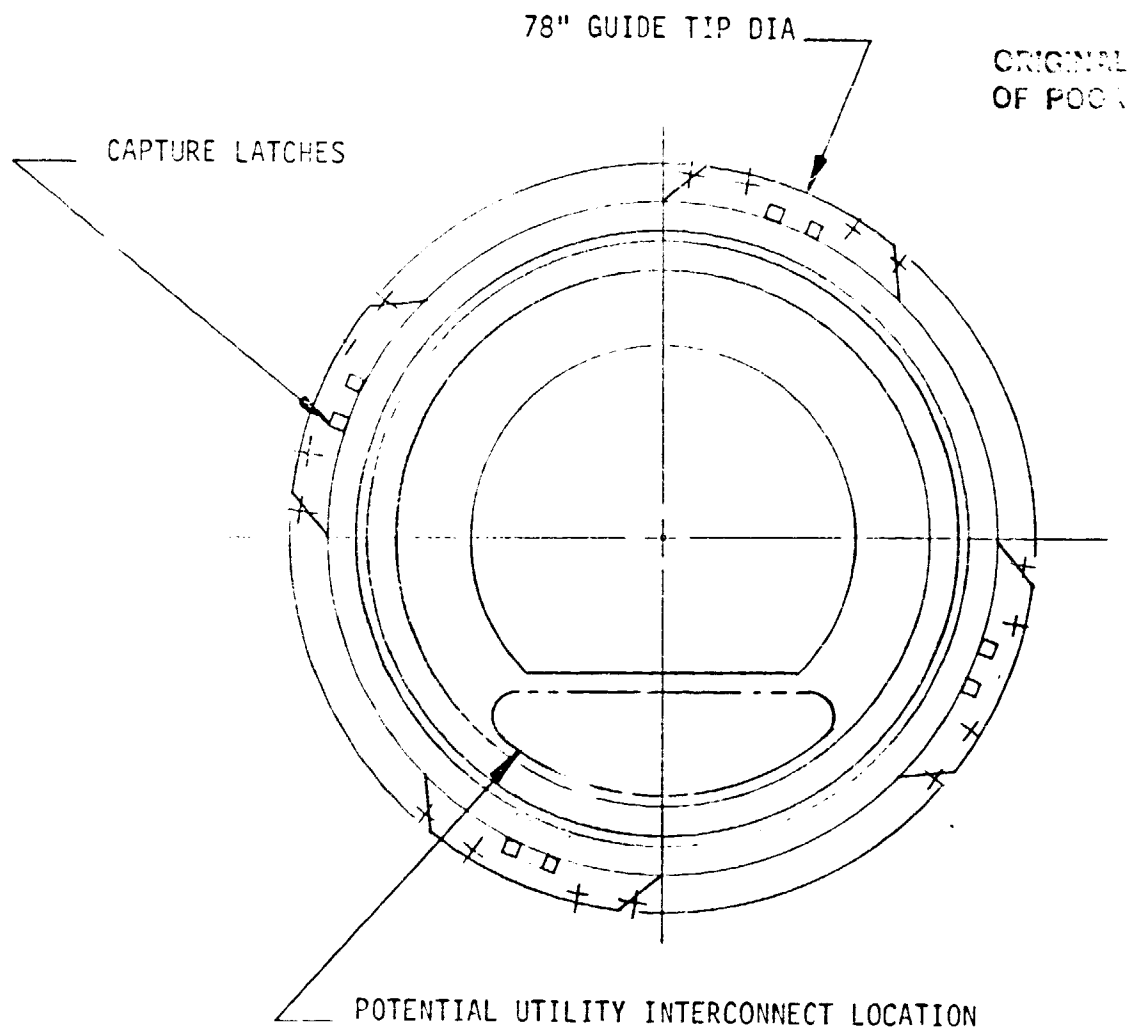


FIGURE 3.4.3.4-1 FOUR GUIDE BERTHING INTERFACE

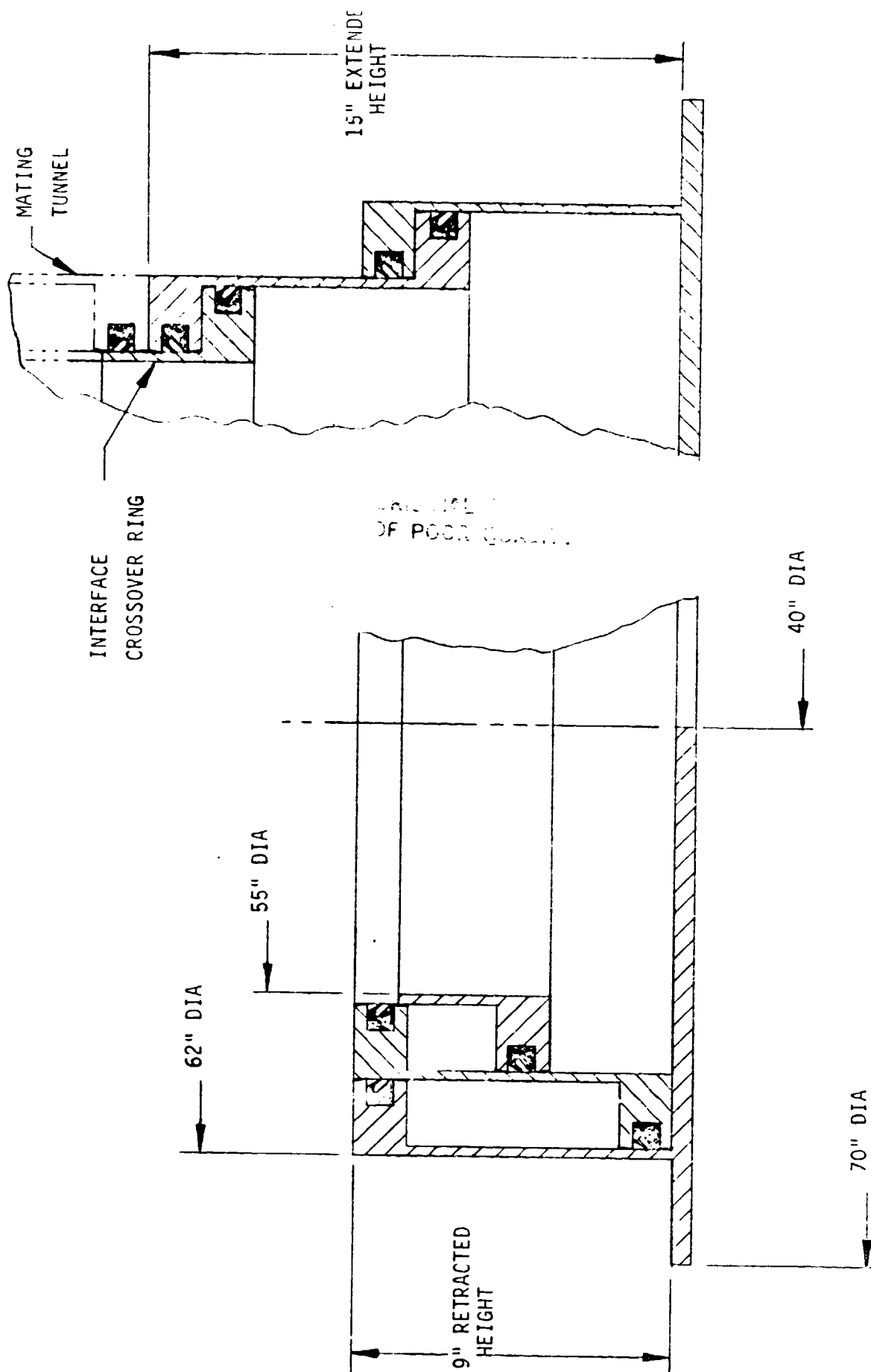


FIGURE 3.4.3.4-2 TELESCOPING TUNNEL

The size and type of utilities interconnects which must cross the berthing interface are shown in table 3.4.3.4-1. Utilities may be routed through the berthing interface in the same manner as for the building block configuration. Alternately, the close proximity of the truss structure provides the option of installing some utilities busses on the truss structure, with independent parallel connections to the modules. This is a natural choice for thermal control since the freon fluid and vapor busses must be located outside the modules and the system is necessarily plumbed with this parallel structure. The advantage of truss mounting the main supply busses is that a module may be removed without interrupting service to the remaining modules. Concepts for truss mounting of the electrical power and thermal transport busses are described in section 3.4.3.4.4.

3.4.3.4.3 Array Truss Rotary Joint

For optimum energy collection efficiency, the array truss must be rotated $\pm 17^\circ$ relative to other station elements. The energy storage and conditioning truss (beam) is therefore mounted to the vertical truss through a system of hinges and linear actuators as shown in figure 3.4.3.4-3 and 3.4.3.4-4. These hinge and actuator mechanisms must be designed as much for ease of assembly as for assembled function. Attachment of the mechanisms to the truss structure will be as described in section 3.4.3.4.5. Details of the assembly process and details of mechanisms design have not been developed. The power system radiators are mounted on the array truss and radiators for other elements are mounted on the vertical truss such that thermal control fluid and vapor loops do not cross the rotary joint. As the energy storage and conversion (ES/C) modules are also mounted on the array truss, only AC power must be delivered across the rotary joint. Flexible couplings should accommodate the required $\pm 17^\circ$ rotation.

NAME	NO.	TYPE	COMMODITY	QUANTITY	UNITS	SIZE	MATERIAL
FREON SUPPLY	1	H. PRESS. LIQ.	FREON	2500	LB/HR	1" ID. TUBE	S. STEEL
FREON RETURN	1	L. PRESS. BI-PH.	FREON	2500	LB/HR	2" ID. TUBE	S. STEEL
COOLANT SUPPLY	1	L. PRESS. LIQ.	WATER	500	LB/HR	3/4" ID. TUBE	S. STEEL
COOLANT RETURN	1	L. PRESS. LIQ.	WATER	500	LB/HR	3/4" ID. TUBE	S. STEEL
DRINKING WATER	1	L. PRESS. LIQ.	WATER	50	LB/DAY	.5" ID. TUBE	S. STEEL
WASTE WATER	1	L. PRESS. LIQ.	URINE/FLUSH	100	LB/DAY	.5" ID. TUBE	S. STEEL
OXYGEN SUPPLY	1	MED. PRESS. GAS	OXYGEN	20	LB/DAY	3/8" ID. TUBE	S. STEEL
NITROGEN SUPPLY	1	MED. PRESS. GAS	NITROGEN	5	LB/DAY	1/4" ID. TUBE	S. STEEL
WASTE WATER	1	L. PRESS. LIQ.	CONDENSATE	3	LB/HR	1/2" ID. TUBE	S. STEEL
WASH WATER	1	MED. PRESS. LIQ.	GRAY WATER	150	LB/DAY	1/2" ID. TUBE	S. STEEL
AIR SUPPLY	1	LOW PRESS. GAS	AIR	150	CFM	4" ID. TUBE	COMPOSITE
DATA ACQ/TLM	4	MULT. COND. CABLE	DIGITAL DATA	--	--	40 WIRE CONN.	-----
T. C&N CNTRL/STATUS	4	MULT. COND. CABLE	DIGITAL DATA	--	--	8 WIRE CONN.	-----
AUDIO CONTROL	2	FIBER OPTIC	DIGITAL DATA	--	--	1/2" DIA. CONN.	-----
AUDIO SIGNAL	2	FIBER OPTIC	DIGITAL DATA	--	--	1/2" DIA. CONN.	-----
REGIONAL DATA BUS	4	FIBER OPTIC	DIGITAL DATA	--	--	1/2" DIA. CONN.	-----
POWER. DIST. CNTRL BUS	4	FIBER OPTIC	DIGITAL DATA	--	--	1/2" DIA. CONN.	-----
POWER SUPPLY	4	INDUCTIVE	HIGH VOLT. AC	25	KW	6" DIA. CONEPAIR	-----
WISC. DATA BUS	8	FIBER OPTIC	DIGITAL DATA	--	--	1/2" DIA. CONN.	-----

TABLE 3.4.3.4-1 INTERMODULE UTILITIES INTERFACES

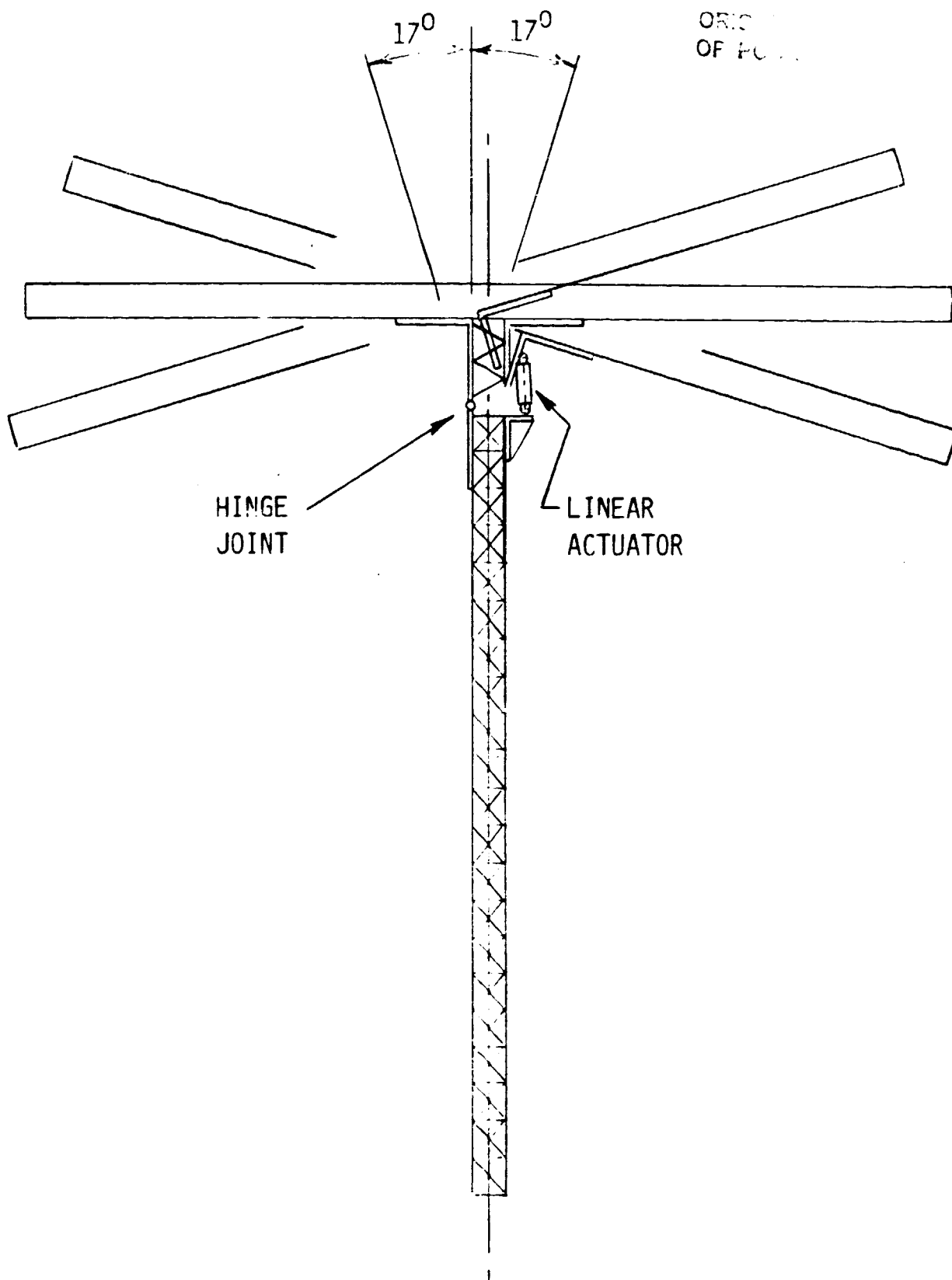


Figure 3.4.3.4-3. "T" Configuration
Pivot Joint Concept

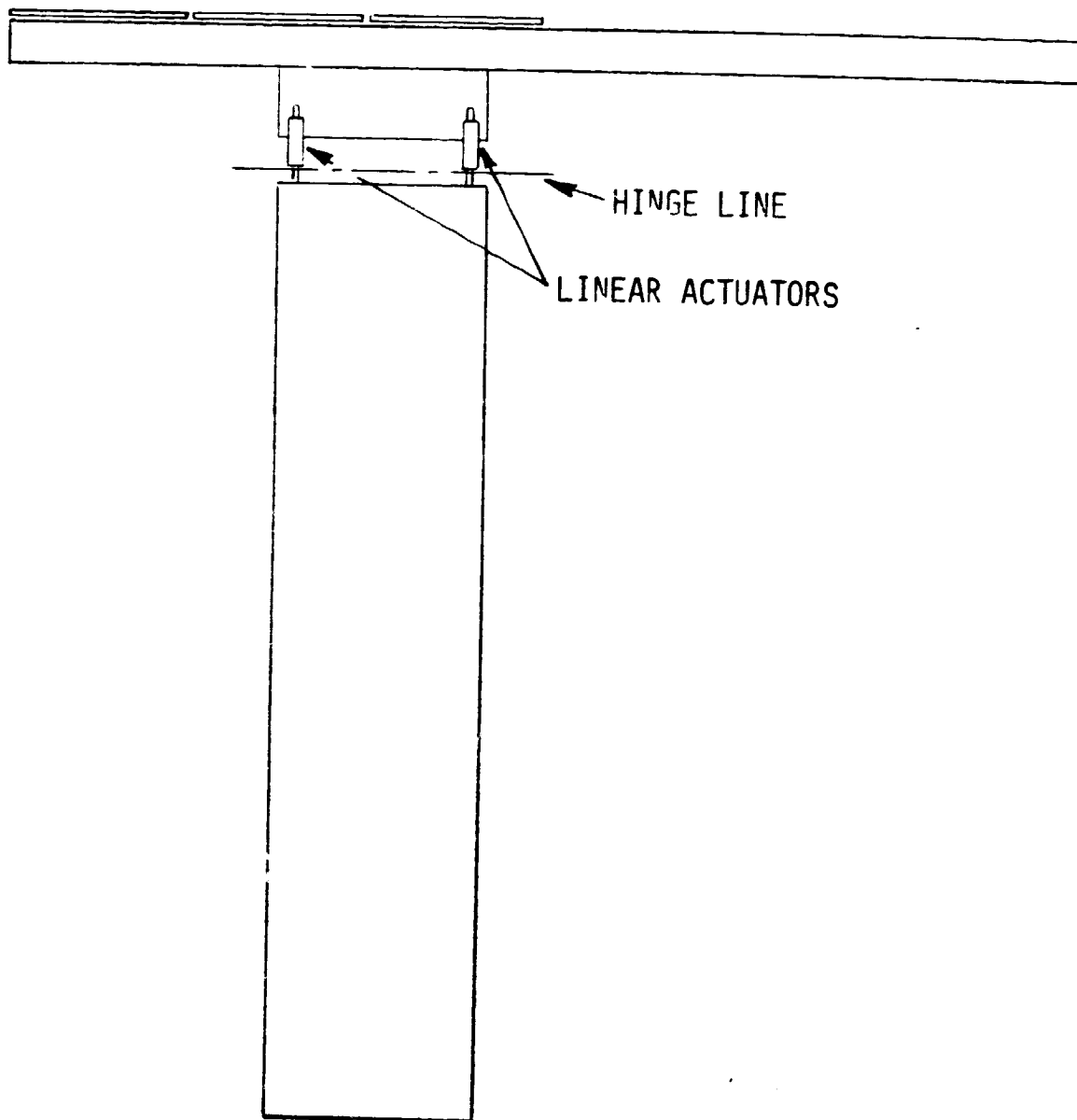


Figure 3.4.3.4-4 "T" Configuration Pivot
Joint Concept

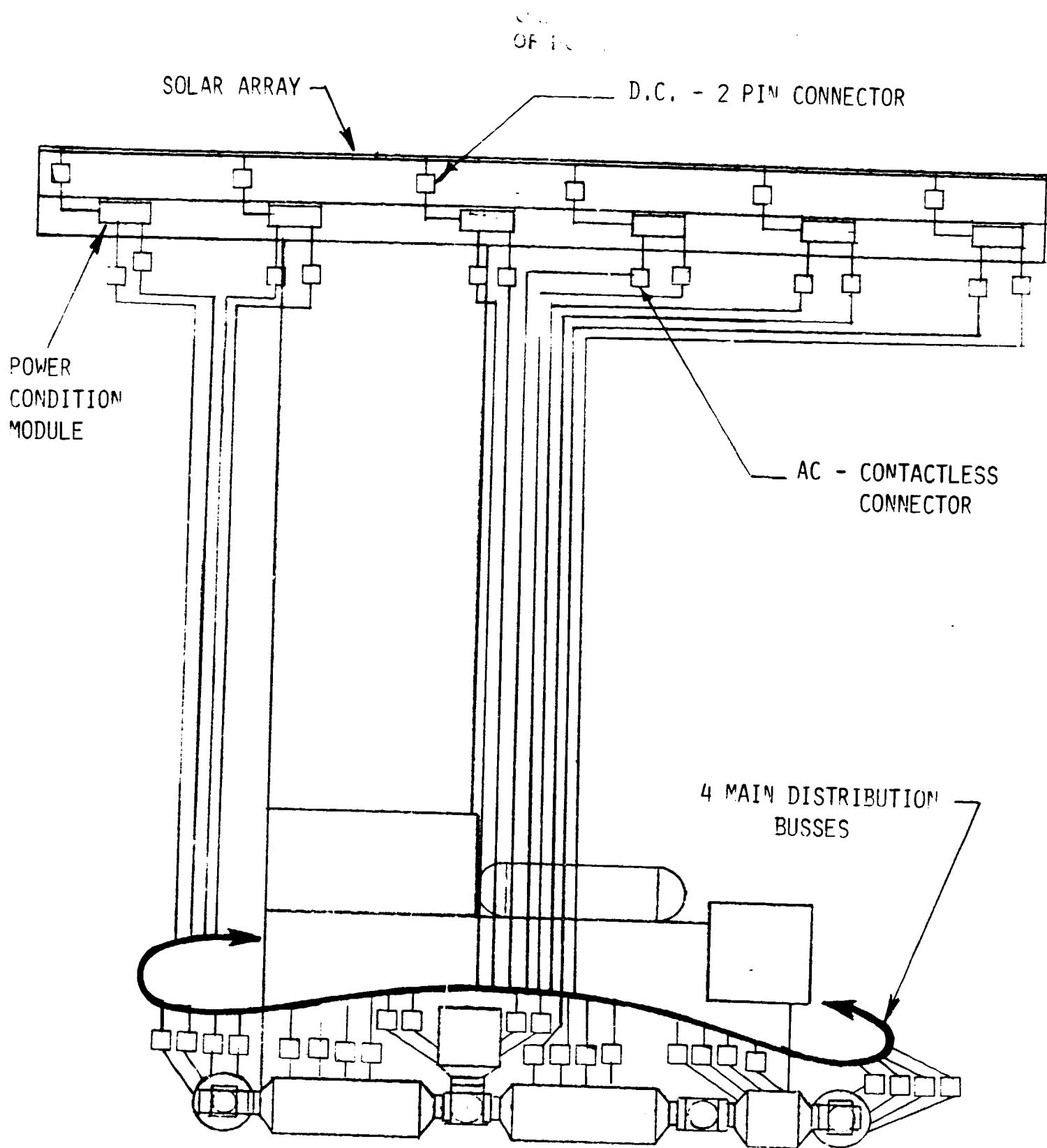


Figure 3.4.3.4-5. Power Distribution Concept - "T" Configuration

3.4.3.4.4 Truss Mounted Utilities Interfaces

Figure 3.4.3.4-5 illustrates a concept for power distribution from the solar arrays to the various modules. The solar arrays and ES/C modules are located on the array truss. DC power is delivered from the solar arrays to the ES/C modules with two pairs of #4 wire with two pin connectors at each end as shown. The power is converted at this point into three phase 400 VAC and four distribution busses are routed from each ES/C module down near the base of the vertical truss structure. These four busses are connected to a main distribution four bus system which is attached to and encircles the truss structure. Each module is then connected to these main distribution busses. Each module will contain four distribution busses for redundancy. Only two busses will be activated as supply busses at a given time. All connections within the AC power distribution circuit will be made with contactless (inductive) connectors.

Installation of the power distribution system need not involve stringing wire. Prior JSC study efforts proposed use of cable trays which could be attached to the truss elements with simple push on clamps. Cable runs longer than the Orbiter PLB could be accommodated with folding cable tray assemblies. Many details remain to be worked, but placement of the power distribution system using the manipulator does not appear impractical. EVA may be more attractive for connecting the various elements.

Details of the thermal transport concept are less well developed. Freon fluid and vapor busses must be connected from the truss mounted radiators to the various modules. Schematically, the concept is the same as for power distribution. Fluid and vapor lines will be routed from the radiators to main busses which are attached to and encircle the truss structure near the location of the modules. Each module will be independently connected to the

main busses; therefore, removal of a module will not interrupt service to the other modules. A typical module connection arrangement is shown in figure 3.4.3.4-6. Precharged line segments will be mounted to the truss structure and connected to form the thermal transport system. Use of tubing trays which easily attach to the truss structure may simplify the placement process but many connections must be made and verified. Significant EVA, or manipulator assisted EVA, may be required.

3.4.3.4.5 Element-to-Truss Attachment

Large elements must be attached to the truss structure at the nodes where significant loads can be tolerated. The nodes will be designed to accept quick operating push in (pip pin) connectors and more sophisticated connectors capable of withstanding higher tensile loading. For low mass items such as cable trays, simple push on clamps which attach directly to the truss elements (approximately 2" diameter tubing) may be adequate.

Each special truss attachment requirement must be worked in detail. Prior JSC studies identified several practical attachment concepts, including multiple tripod arrangements for attaching modules (or the OTV). For this study, a tripod module attachment scheme was evaluated for the purpose of weight estimation. Four tripods are employed with each of the 12 legs attached to a truss node. Four lightweight retention fittings, which interface with the standard trunnions used to mount the module in the PLB, are attached to the upper ends of the tripods. Estimated weight for this concept is 0.5% of the attached module weight, so an attachment weight penalty of 0.5% of the weight of all elements attached to the truss was assessed.

The number of nodes available for attachment is quite limited so detailed design of attachment concepts will be an important process and one which may influence slight modifications in station element placement.

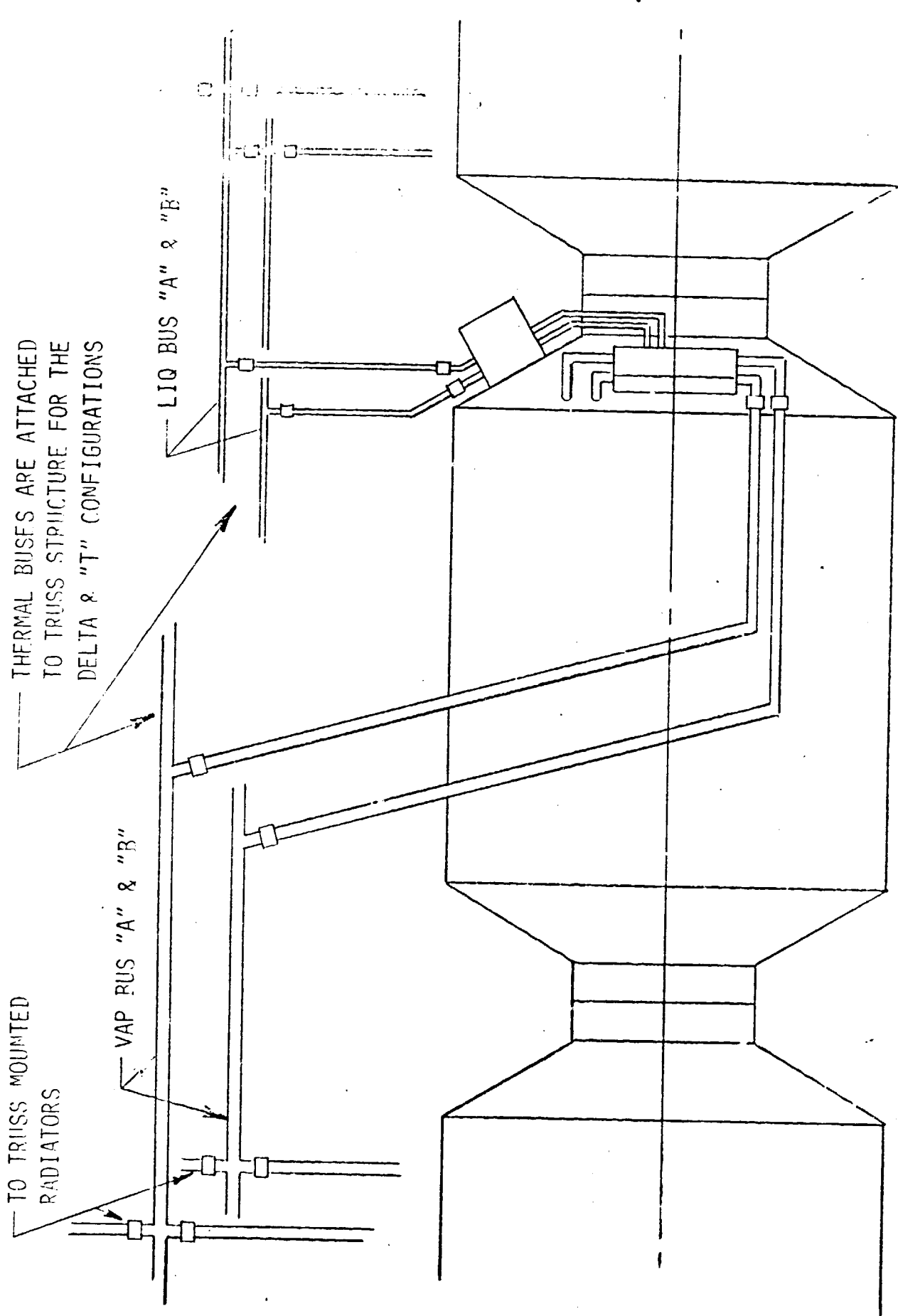


FIGURE 3.4.3.4-6 THERMAL CONNECTIONS SCHEMATIC
TYPICAL ARRANGEMENT FOR
DELTA & "T" CONFIGURATION

Certain nodes are exposed in the packaged condition of the truss. These nodes are ideal for attachment, prior to deployment, of one or more manipulator grapple fixtures to facilitate assembly.

Of particular interest for the "T" configuration is the assembly of the rotary joint between the array truss and the vertical truss. The hinges and actuators must be attached to load carrying nodes so the geometry of attachment bracketry is restricted. It may be necessary to bypass the rotary joint elements with a more easily accomplished temporary attachment to hold these large structures in place while the rotary joint is completed.

3.4.3.4.6 Manipulator Systems

The Space Station manipulator will be the standard Orbiter RMS unless further detailed evaluation of the assembly process establishes the need for greater reach capability. The RMS shoulder will be mounted to a berthing interface mechanism modified to accommodate RMS power and control utilities only.

Through the berthing interface, the manipulator may be stationed at any available berthing port. A special manipulator berthing port will be mounted to the vertical truss structure in position to aid in station assembly and to service the OMV hangar. Two additional manipulators will be located to service the added hangars and the satellite servicing facility on the growth configuration.

3.4.3.4.7 Hangar and Satellite Servicing Mechanisms

The OMV and OTV hangars will be attached to the vertical truss structure. All hangar doors will be provided with conventional hinge, latch, and drive mechanisms. The satellite servicing area comprises beams attached to the vertical truss structure. The beams, representative of the Orbiter PLB longerons and keel, will incorporate lightweight Orbiter payload retention

fittings which mate with standard trunnion fittings on large satellite elements. The OMV and OTV hangars will include similar beam assemblies. Utilities will be brought to the service/storage facilities from the main utilities busses, as for modules.

3.4.3.5 Thermal Control Concept Evaluation

3.4.3.5.1 Introduction

Engineering evaluation considerations considered during this study were:

- o Vehicle thermal environment (i.e., view factors, blockage, heat fluxes)
- o Radiator area requirements
- o Orbiter impacts
- o Design complexity
- o Verification complexity
- o Surface contamination sensitivity
- o Hardware commonality
- o Technology status

The following discussions will present a system overview and will assess how well the "T" vehicle configuration satisfies these factors.

3.4.3.5.2 System Overview

The candidate Active Thermal Control Subsystem (ATCS), schematically illustrated by figure 3.4.3.5-1, is a hybrid design concept that maximizes the use of local thermal control for individual station modules and satisfies the remaining thermal control requirements with a centralized system. Each station module will contain a heat collection and transport system similar in function to the Shuttle Orbiter cabin design (i.e., a pumping system, coldplates, heat exchangers, plumbing lines and flow control valves). These

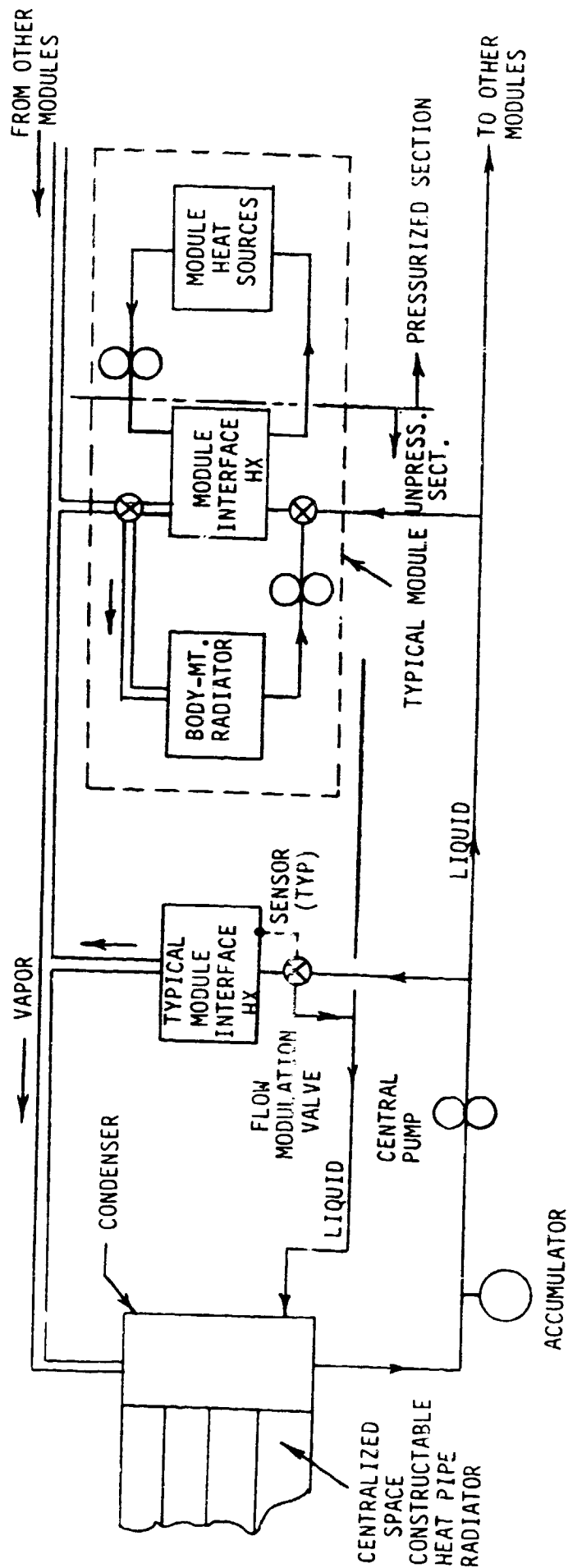


Figure 3.4.3.5-1. Active Thermal Control Subsystem Concept

individual station module systems will be integrated with a central transport system. In addition, each station module will have heat pipe space radiators (operating at about 70°F) integrated with the module meteoroid protection shield. The size of these radiators will vary from module to module depending on surface area availability considering docking ports, windows, thermal blockage, etc.

When waste heat in a station module exceeds its thermal capacity, the excess heat will be transferred to a central collection and transport circuit for delivery to a central truss-mounted radiator attached in the near vicinity of the station modules. A separate high temperature radiator (operating at about 160°F) will be attached to the underside of the solar array truss to reject electrical power system waste heat. Because the transport circuit (or "thermal bus") uses a two-phase working fluid that transfers heat by evaporation and condensation rather than by sensible heat changes of a single phase coolant, it operates at a constant temperature over the entire length of the loop. Furthermore, this "thermal bus" is capable of transporting large thermal loads over long distances with pumping requirements that are very small compared to single phase fluid systems. Table 3.4.3.5-1 summarizes the IOC weight and power estimates for the candidate ATCS concept.

A vehicle thermal system design which judiciously applies thermal coatings, vacuum type insulations, isolators, and heaters will be selected for those systems and elements which are not integrated into the ATCS. The system will be selected to minimize the addition of electrical heat for thermal control purposes. The systems which appear to require such a design, at this time, are the communications (antennas), propulsion remote manipulator, and control moment gyros. Heaters in these systems will eliminate thermostats and their

Table 3.4.3.5-1. IOC Active Thermal Control
Subsystem Characteristics

STATION ELEMENT	WEIGHT (LBS)		POWER (KW)
	DRY	WET	
C/C ₁	1,345	1,465	0.33
LAB ₁	2,621	2,945	0.89
LAB ₂	1,803	2,002	0.52
HAB ₁	2,452	2,591	0.33
LOG ₁	485	514	0.06
MODULE* TRUSS	10,785	10,915	0.22
POWER SYSTEM TRUSS**	4,139	4,269	0.16
TOTALS	23,630	24,701	2.51

*TRUSS-MOUNTED RADIATORS AND ASSOCIATED TRANSPORT SYSTEM LOCATED
ADJACENT TO STATION MODULES.

**TRUSS-MOUNTED RADIATORS AND ASSOCIATED TRANSPORT SYSTEM LOCATED
ON UNDERSIDE OF "T" SOLAR ARRAY STRUCTURE.

inherent failure modes by using sensors to feed software logic for heater control.

An insulation/coating system will be selected for the habitable areas and power generation systems which compliments the active heat rejection systems. Insulations and coatings will be applied to unpressurized areas such as the satellite service structure, OMV and OTV hangars in order to bound the thermal environments within the payloads design envelopes thereby minimizing operation of the payload thermal/control systems and station power requirements.

Virtually all elements of the "T" configuration receive direct solar energy and will require surface treatments with low solar absorption of emissivity ratios to limit structural temperatures and heat leak into the element. This requires the application of paints and films since this cannot be achieved with treated metal surfaces. Surface property degradation is discussed in section 4.2.2.3.

The insulation system is envisioned as similar to the high performance multilayer insulation design applied to the Orbiter vehicle except having as many as 20 layers of organically coated aluminized film as opposed to the 10 layers in the Orbiter design. This results in a weight of approximately 0.25 pounds per square foot including mesh separators, attachments, venting provisions, and cover material. The insulation weight for the "T" IOC and growth configurations are 4,260 and 10,920 pounds respectively.

Local protection from RCS engines plume heating will be required. The extent of the protection and its impact on design will depend on engine firing requirements.

The propellant tanks of the monopropellant hydrazine propulsion system will be individually mounted on the command module and each will be maintained within

temperature limits through passive thermal control. For the hot environment, each tank (3.5 foot diameter) will be maintained below its upper temperature limit by use of insulation and an appropriate coating. For the cold environment, each tank and the fuel distribution system will be maintained above its lower limit by the use of insulation and heaters. The heater wattage needed for this purpose is shown in table 3.4.3.5-2.

Preliminary design indicates that the 25 pound thrusters will be placed in clusters of 12 thrusters each and will be mounted on the command module next to the propellant tanks. Passive thermal control of the thrusters and their feedlines will be achieved through insulation of the cluster and the use of heaters for the engines and lines. Heater wattage needed is shown in table 3.3.3.5-2.

The thermal control heaters for the propulsion system are sized based on a 50% duty cycle.

TABLE 3.4.3.5-2
PROPULSION SYSTEM HEATER REQUIREMENTS

CONFIGURATION	TANKS & FUEL DISTRIBUTION			THRUSTERS & FEEDLINES	
	# TANKS	TOTAL AREA FT	HEATERS WATTS	# THRUSTERS	HEATERS WATTS
"T" - IOC	4	154	431	24	960
"T" - GROWTH	4	154	431	24	960

The passive thermal control design of the antennas is similar to that of the Orbiter Ku-band antenna. Each electronics box will be of minimal thickness with the electronics mounted directly to a cold plate radiator located on the large face of the box. The box will be covered with silvered teflon with an absorptance/emittance (α/ϵ) = .13/.8 . The radiator area for each electronic

box and internal heat generation for each different type of antenna is shown in table 3.4.3.5.-3. Also shown in this table is the heater wattage needed in each electronic package to keep the electronics above their minimum temperature.

The heater wattage needed to maintain the gyros, gimbals, and comparator of the S/Ku-band steerable dishes above their minimum temperatures are shown also in table 3.4.3.5-3. The heaters for maintaining minimum temperatures are sized based on a 50% duty cycle. Antenna heater operation will only occur when the antenna is off two hours or more.

TABLE 3.4.3.5-3
IOC BIG "T" ANTENNA THERMAL CHARACTERISTICS

ANTENNA TYPE	ELECTRONICS PACKAGE FOR EACH ANTENNA					TOTAL			ANTENNA COMPONENTS	
	NO	TEMP LIMITS F°	INT. HEAT GEN. WATTS	RADIATOR AREA FT²	THERMAL CONT. HTRS* WATTS	HEATERS WATTS	WATTS	WATTS	HEATERS WATTS	TOTAL WATTS
S-BAND MED GAIN P.A.	1	32-131	335	11.2	525	525	---	---	---	---
K-BAND HIGH GAIN MULTI P.A.	2	32-131	250	8.4	394	788	---	---	---	---
K-BAND MED GAIN P.A.	1	32-131	175	5.9	277	277	---	---	---	---
S/KU-BANDS STEERABLE DISH	1	130-152	250	8.4	394	394	230	230	---	230
L-BAND WIDE BEAM	1	0-191	45	1.5	70	45	---	---	---	---
K-BAND HIGH GAIN P.A.	2	32-131	85	2.8	131	262	---	---	---	---
						TOTAL	2,316	---	---	230

GROWTH BIG "T" ANTENNA THERMAL CHARACTERISTICS

S-BAND MED GAIN P.A.	1	32-131	335	11.2	525	525	---	---	---	---
K-BAND HIGH GAIN MULTI P.A.	2	32-131	250	8.4	394	788	---	---	---	---
K-BAND MED GAIN P.A.	3	32-131	275	5.9	277	1,108	---	---	---	---
S/KU-BANDS STEERABLE DISH	1	130-152	250	8.4	394	394	230	230	---	230
L-BAND WIDE BEAM	1	0-191	45	1.5	70	70	---	---	---	---
K-BAND HIGH GAIN P.A.	10	32-131	85	2.8	131	1,572	---	---	---	---
						TOTAL	4,457	---	---	230

* HEATERS SIZED FOR 50% DUTY CYCLE

3.4.3.5.3 Technical Evaluation

3.4.3.5.3.1 Thermal Environment

The orbital attitude of the big "T" configuration is a gravity gradient stabilized earth-oriented mode. This causes constant terrestrial IR fluxes to be impinging upon structures which are continually viewing the earth's surface. Solar and albedo fluxes would be somewhat cyclic throughout the orbit.

Shading of the modules and radiators from the sun by the solar array will occur during only a portion of the orbit so adequate performance of thermal coatings will be required. This problem becomes more severe at high solar Beta angles due to the fact that the solar array does not shade the modules or radiators on the sunward side of the truss. Therefore, the configuration was analyzed at 52° Beta with the solar array pitched down 20° to understand what impact a worst case thermal attitude would have on the thermal control system architecture.

Orbital average incident thermal flux levels at Beta = 52° are shown for the big "T" configuration in figure 3.4.3.5-2. Values given for the modules are for the 50% of the surface area away from the truss structure. This is representative of the location of body-mounted radiators, though actual placement would be subject to optimization of incident flux, coating performance, and blockage of space viewing factors.

The high incident solar and albedo flux levels on the sunward side module mounted and planar radiators implies that a high performance thermal coating be utilized (i.e. low α/ϵ ratio) to maximize heat rejection capabilities. Due to the differential in flux levels between the module strings and radiators on either side of the supporting truss structure, it would indicate that thermal load sharing be a major feature in the thermal control system

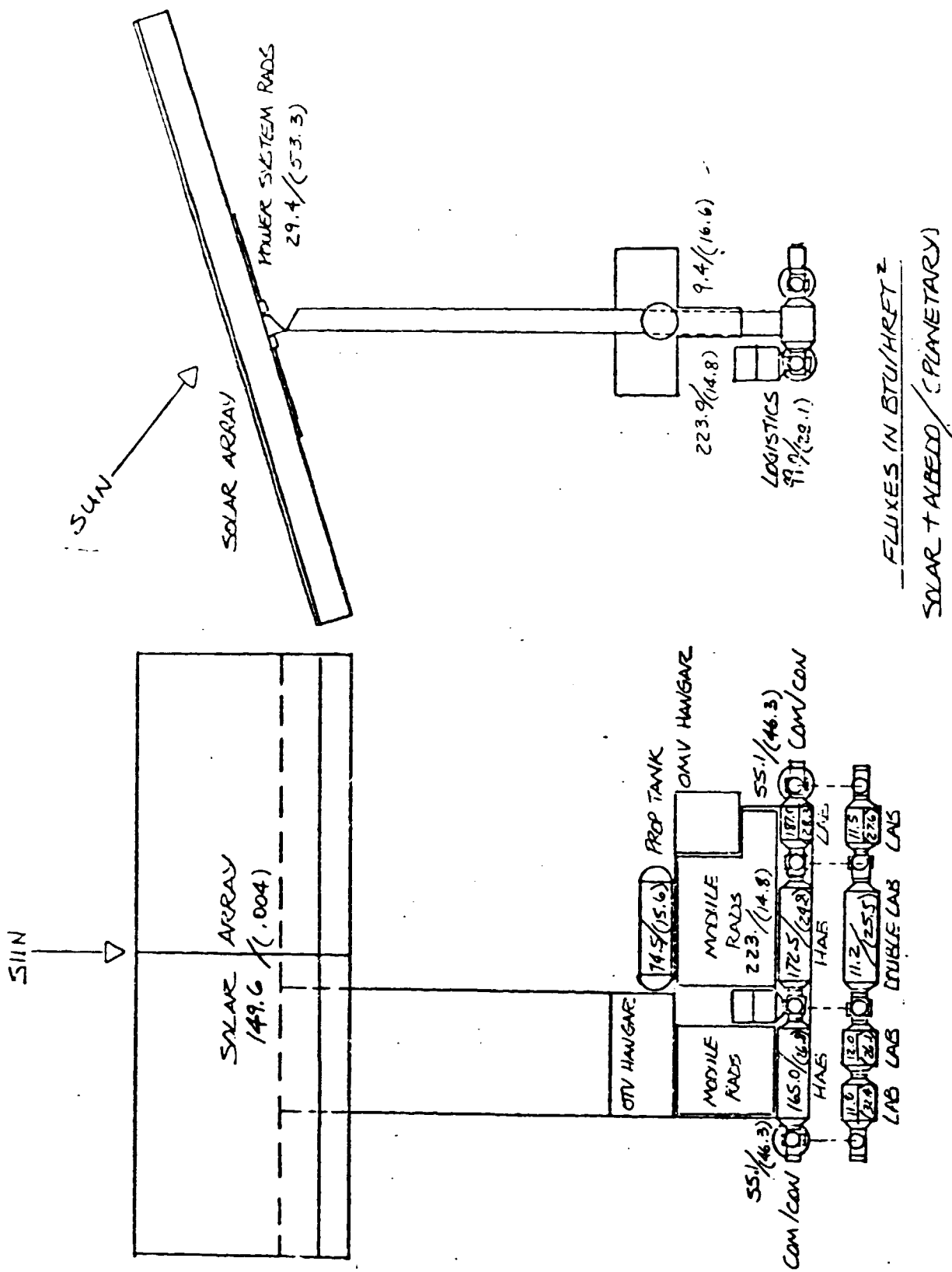


Figure 3.4.3.5-2. Big T Configuration Orbital Average Thermal Fluxes; Beta=520

design.

Figure 3.4.3.5-3 illustrates the average form factors to space for the various structural elements. Space viewing is inhibited predominantly by the large solar array and its pitch angle. Hangar placement next to planar radiator surfaces further reduces radiation to space. The space viewing of the module mounted radiators could be improved somewhat by more precise location than was analyzed in the model. The optimal location would also reduce solar/albedo influences, though terrestrial flux would increase and the total useable area might decrease slightly.

Though the large solar array does block space viewing by the structural elements, it is not a continually hot structure while in the sun. The earth-oriented mode of this configuration provides the array an average orbital temperature of approximately 50°F. This relatively low temperature characteristic permits the power system radiators to be positioned on the surface of the truss structure behind the solar arrays. The local blockage by the power system radiators of solar array backside space viewing could raise affected cell operating temperatures by 20-40°F. How this impacts array operating efficiencies has not been adequately assessed at this time.

The IOC version of the big "T" configuration will have higher space view factors than the growth version, primarily because of the smaller size of the solar array. However, incident solar flux levels will also be slightly higher due to the decreased sun blockage. Thermal interaction between modules should be of little consequence if body-mounted radiators are judiciously placed and high performance multi-layer insulation is used between the outer skin and pressure vessel. The IOC and growth versions of the big "T" should have similar thermal characteristics.

3.4.3.5.3.2 Radiator Areas

Radiator area requirements initially were defined for body-mounted radiators (integrated with station module meteoroid protective shields) to determine heat rejection capabilities for each station module. In general, the effectiveness of the body-mounted radiators is fairly good since blockage from surrounding vehicle elements is not severe as discussed in paragraph

3.4.3.5.3.1. However, it was assumed that 50% of the cylindrical station module wall area was not available for radiators due to interfacing structure with the truss. As a result, body-mounted radiators reject only about 17% of the station total waste heat as summarized in Table 3.4.3.5-4 .

Truss-mounted one-sided radiator panels were sized to reject the balance of the vehicle waste heat not accommodated by the body-mounted radiators. For IOC, truss-mounted radiators with a total radiating area of 7,314 ft² are required to reject the balance of the station module heat loads. A separate set of truss-mounted radiators (operating at about 160°F) are located near the solar array to provide electrical power system heat rejection. Area requirements for the power system radiators are 2,227 ft². For the growth station, the truss-mounted radiators for the station modules increase to 15,095 ft² and to 4,867 ft² for the power system.

The aforementioned radiators were sized to reject the total vehicle waste heat load. Past studies have shown that the use of a thermal storage phase change material can further reduce area requirements when large temperature transients are encountered. These transients normally result from widely varying environmental heat fluxes and/or internally generated vehicle waste heat. For this study, the power system radiators were selected to illustrate the potential application of thermal storage.

Because of the difference in day/night times and the difference in

efficiencies between the fuel cell modules and the electrolysis modules, the night time heat load for the power system is much greater than the day time heat load. As mentioned, if part of the night time heat can be stored in a phase change material for rejection during the day time, the power system radiator area can be reduced further. One candidate for a phase change thermal storage material for the regenerative fuel cell heat rejection system is Barium Hydroxide Octahydrate. Its density is 136 lb/ft³, melting point is 172°F, and latent heat is 129 btu/lb.

Preliminary analysis shows that the use of 236 lb. of this phase change material would reduce the required remote radiator area by about 30%*.

Required radiator area and capability and applied heating loads without and with thermal storage are shown in figures 3.4.3.5-4 and 3.4.3.5-5 respectively. Although the weight of the phase change material and associated hardware will probably be equivalent to the radiator weight reduction, other design considerations such as view factors and blockage may still favor the use of thermal storage material. In addition, a thermal storage approach permits a non-articulated radiator to be a viable station option.

(* Power system waste heat characteristics used in the thermal storage evaluation were not the same as used in the final radiator sizes documented earlier; however, the general conclusions reached and relative savings demonstrated are valid.)

3.4.3.5.3.3 Orbiter Thermal Control Impacts

While the Shuttle Orbiter is docked to the station, heat rejection from the Orbiter radiators is reduced about 15% due to blockage from surrounding station elements. This reduction is considered acceptable since the Orbiter probably will be powered down the majority of the time. There are no

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Table 3.4.3.3.5-4
BODY-MOUNTED RADIATOR HEAT REJECTION CHARACTERISTICS*

STATION ELEMENT	IOC			GROWTH		
	WASTE HEAT LOAD (KW)	REJECTION CAPABILITY (KW)	AVAILABLE AREA (FT ²)	WASTE HEAT LOAD (KW)	REJECTION CAPABILITY (KW)	AVAILABLE AREA (FT ²)
C/C ₁	9.8	3.6	323	10.1	3.6	323
C/C ₂	--	--	--	8.2	3.6	323
HAB ₁	8.6	10.1	807**	10.1	10.1	807**
HAB ₂	--	--	--	8.5	10.1	807**
LAB ₁	45.5	4.1	323	46.0	4.1	323
LAB ₂	24.5	4.1	323	25.0	4.1	323
LAB ₃	--	--	--	36.2	9.5	807**
LAB ₄	--	--	--			
LAB ₅	--	--	--	18.1	3.2	323
LAB ₆	--	--	--	18.1	3.2	323
TOTALS	88.4	21.9	1776	180.3	51.5	4359

*Total vehicle waste heat loads: 137KW (IOC)
(Neglecting Comm/Tracking) 277KW (Growth)

**Long Module

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STREAMLINE TRUSS MOUNTED F/C RADIATOR

WITHOUT THERMAL STORAGE (1613 FT²)

□ .RAD. CAPABILITY TO SPACE
 × .RFC LOAD
 △ .ABSORBED ENVIRONMENTAL
 ○ .SOLAR ARRAY "LOAD"
 ◇ .TOTAL RFC + ENVIRONMENTAL + ARRAY

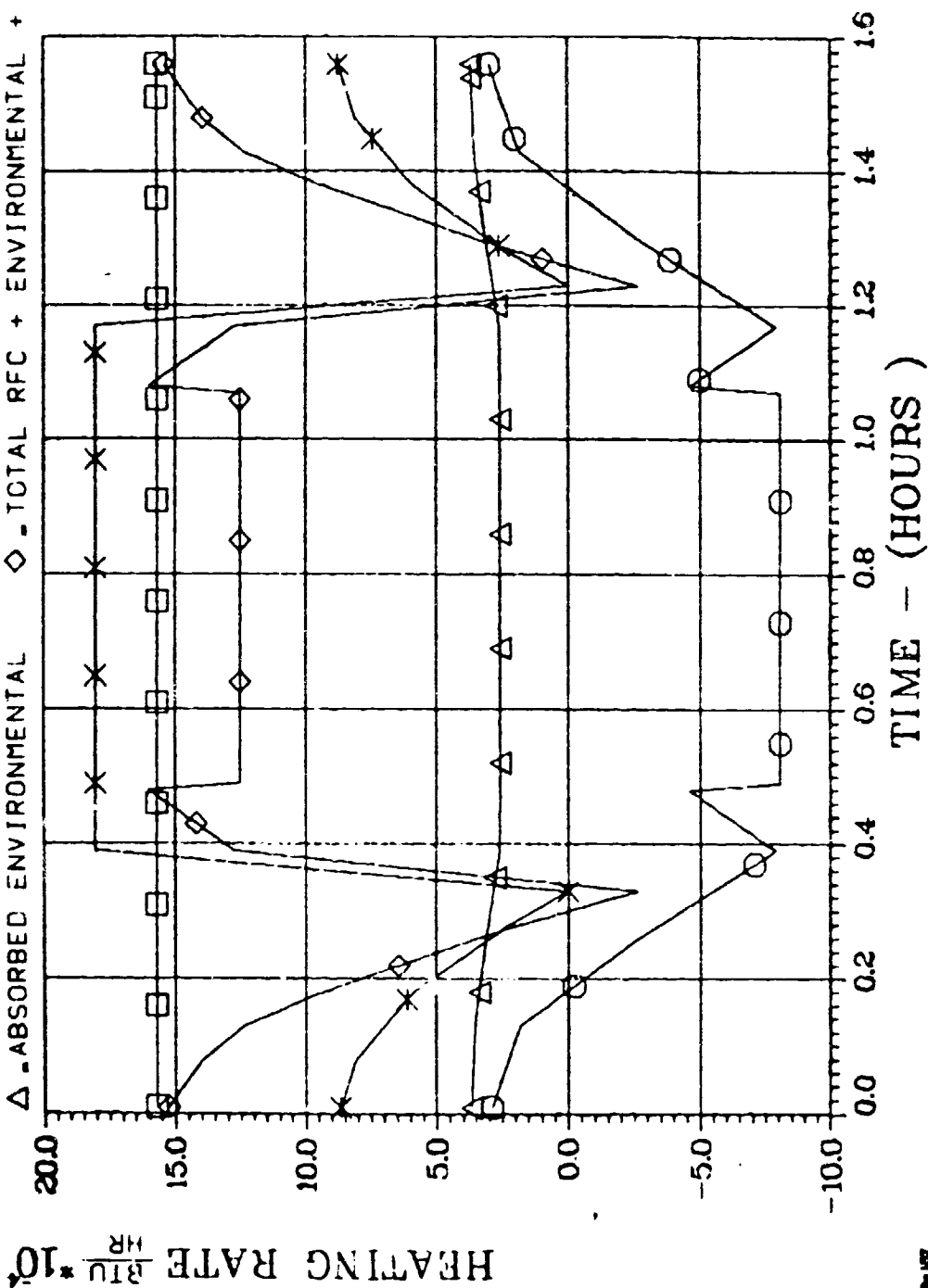


Figure 3.4.3.5-4

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STREAMLINE TRUSS MOUNTED F/C RADIATOR

WITH THERMAL STORAGE (1138 FT²)

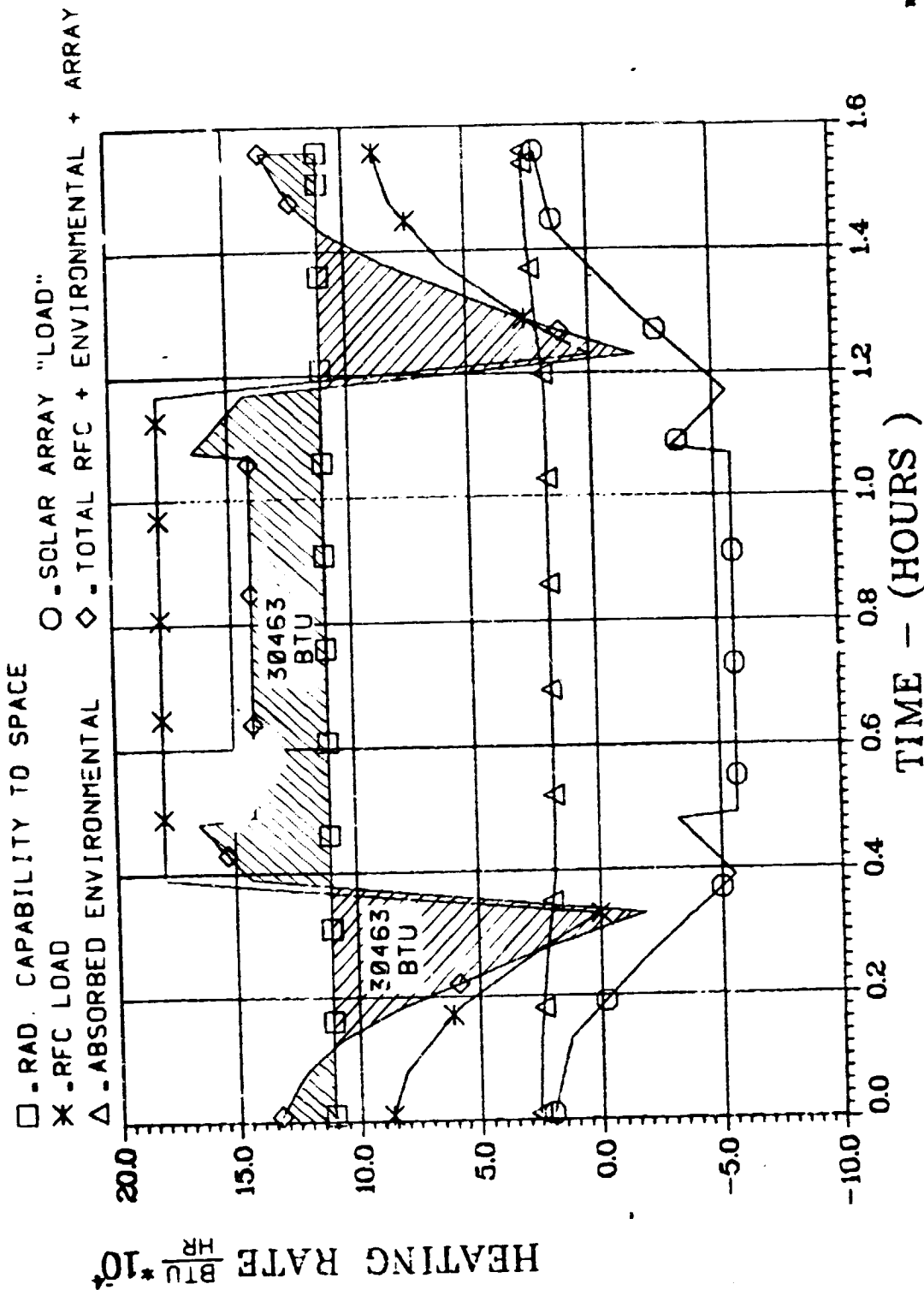


Figure 3.4.3.5-5

additional Orbiter thermal control impacts that can be identified at this time.

3.4.3.5.3.4. Design Complexity

The primary design complexity involves the launch packaging, on-orbit construction, and activation of the truss-mounted radiators. This operation will require RMS to:

1. Remove radiator contact heat exchanger modules and radiator elements from the Orbiter payload bay
2. Install contact heat exchanger modules on the station truss,
3. "Plug in" radiator elements into the contact heat exchanger. EVA support probably will be required to make final fluid line connections.

3.4.3.5.3.5 Verification Complexity

Component level verification should follow that of previous programs with the possible exception of life cycle tests. Items which fall into this category are insulations, coatings, heater system components, and fluid distribution system components. These tests with the possible exception of the heat pipe radiators do not appear any more complex than those of past programs.

The question of verification complexity in the thermal area arises from verification of the integrated thermal control design of the Space Station.

The recommended approach is to baseline ground thermal testing of typical elements and interfaces based on design commonality (to the fullest extent possible) supplemented by Orbiter in-bay or deployed testing of items such as heat pipe radiators requiring unique environments. Testing during the Space Station buildup would be limited to checkout type tests.

Since the thermal verification approach is not highly configuration dependent, additional discussion is presented in the Subsystem Definition Section, section 4.2.

3.4.3.5.3.6 Surface Contamination

A high probability of thermal control surface degradation exists as a result of the close proximity of RCS engines to station modules. Most surface treatments are expected to exhibit and require low solar absorptivities which will increase as a result of plume impingement.

The distance from RCS engines to radiators and solar panels should minimize contamination of these surfaces. However, detailed analyses are required to determine acceptability.

3.4.3.5.3.7 Big "T" TCS Commonality

o Within Space Station

The gravity gradient stabilized orbital attitude of the big "T" Space Station configuration causes similar thermal environments to be incident on the modules when averaged over the Beta angle cycle throughout the orbital year. High incident solar fluxes on one side of the module strings at high positive Beta angles will be incident on the opposite side for high negative Beta angles. Therefore, the thermal control system will probably be designed for environments at a median to these extremes with a full capability designed to compensate for the total range. Since both module strings will have this common design environment, placement of body-mounted radiators and selection of thermal coatings will hold for both strings. The primary variables will be the amount of internal equipment requiring thermal control and the consolidated heat load to be rejected from each module.

However, the command and control modules will experience somewhat different environments from the other modules. Also, the C/C modules are mounted on the side of the truss structure, preventing deployment of supplemental radiator surfaces, as is possible with the module strings attached to the truss surface. These differences decrease the overall TCS commonality to a small

degree as thermal load sharing between modules will most likely be the design architecture followed.

Power system thermal control will utilize common elements as the system grows. Radiators located at the outer edge of the solar array will have a better view to space and, as a result, need not be as large as those closer to the center of the array. However, the thermal control hardware will be the same from unit to unit.

RCS modules and antenna packages are assumed, at this preliminary stage of design, to share thermal control elements such as electrical heaters, insulation, etc. with the primary vehicle TCS.

o Commonality with platform

Specific thermal control system hardware components (insulation, cold plates, heat exchangers, radiators, etc.) from the big "T" Space Station could readily be incorporated into a free-flying platform. Basic thermal bus architecture would also remain the same or similar if the platform were to require a large thermal control capacity. The greatest divergence from the Space Station TCS would be in heat rejection. If a module concept is utilized in the platform, module-mounted radiators would most probably be used. However, a deployed auxiliary radiator surface may be required to be articulated depending upon the platform orbital attitude. If the articulation of radiators is required, a fluid swivel or thermal slip ring, which is not requisite for the station heat rejection, must be developed.

The utilization of high performance thermal coatings could be more critical on the platform than on the big "T" Space Station. This is assuming that the platform is not in the same configuration or orbital attitude as the station, thereby allowing greater solar impingement on associated structural elements.

The degree of thermal coating performance is dependent upon the actual platform configuration and orbital attitude.

3.4.3.5.3.8 Technology Assessment

No vehicle unique technology requirements were identified. The on-going OAST-sponsored thermal technology program is further discussed in section 4.2.2.8.

3.4.3.6 Power Evaluation

3.4.3.6.1 Introduction

The Power System consists of three subsystems: Energy Conversion Subsystem (ECS), Energy Storage Subsystem (ESS), and Power Management and Distribution subsystem (PMAD). For the "T" configuration, the power system was designed to supply an average of 75 KW at IOC and 150 KW for the growth phase station is reached. The system was designed with the following groundrules:

1. Ten year operational life was a design goal for the various components.
2. A modular buildup scheme was used where practical.
3. Module changeouts were permitted to achieve the 10 year operational life of the components and the extended life of the station.
4. EVA was minimized for buildup but was not prohibited.
5. A two hour period was baselined for an emergency energy storage sizing criteria. This would allow for the loss of one complete changing cycle.
6. A gravity gradient flight mode was assumed with 17° of Beta angle correction available. This results in a solar array with approximately twice the area than that of a solar oriented station.

3.4.3.6.2 System Overview

The basic premise of the "T" configuration is to orient the array in such a way so as to minimize the station drag and thus the propellant required for reboost. In order to accomplish this, the array is mounted so that it remains "edge-on" to the velocity vector at all times (see figure 3.4.3.6.2-1). A truss is provided on which the array blankets will be attached. As shown in the illustration, the ESS/PMAD modules are located on the underside of the array truss. This mounting will provide for short wire runs and thermal control radiator mounting. The power transmission lines will have to run 280 feet to the station modules.

Since the array is "edge-on" to the velocity vector, the amount of sunlight reaching the solar cells will vary throughout each light period. This is illustrated in figure 3.4.3.6.2-1, and results in several impacts to the power system:

1. Sunlight is available for only one-half the orbit, which means that the energy storage system must be 25% larger than with other solar oriented systems.

2. The current and/or power from the array will follow a sine curve relation and therefore, the fuel cell component of the ESS will load share with the solar array until the array output reaches the power level required by the station.

3. The ESS/PMAD modules are split in two parts in order to account for the lightside load sharing requirements.

A breakdown of the weights is shown in table 3.4.3.6.2-1. The truss weights are not shown with the ECS solar array.

The "T" configuration will also provide a convenient structure on which to mount the solar array. The "T" will fly such that the array will remain

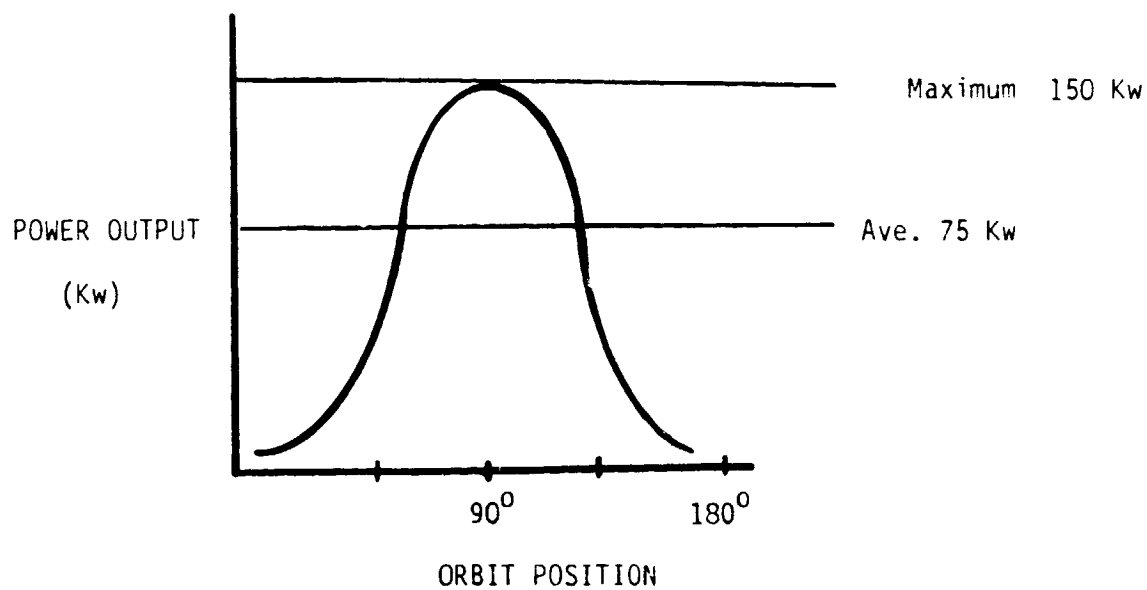
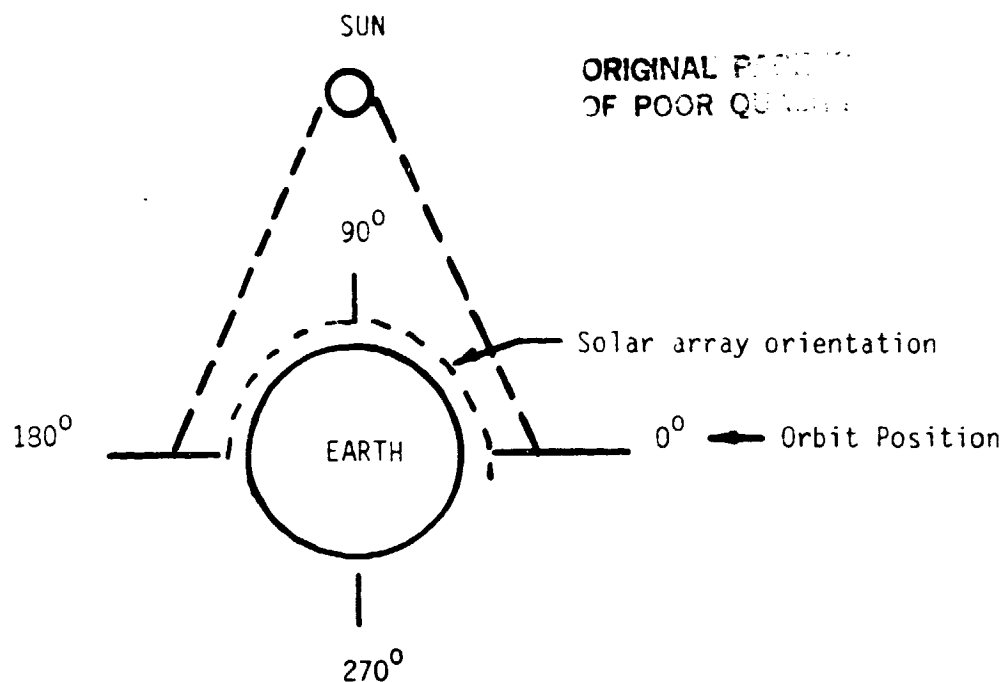


Figure 3.4.3.6.2-2 "T" Configuration Solar Array Output Variations With Orbit Position.

Table 3.4.3.6.2-1. "T" Configuration Power System Characteristics

SOLAR ARRAY (ECS)

	Weight (lbs)	Area (ft ²)
IOC	9,000	30,000
Growth	18,000	60,000

REGENERATIVE FUEL CELL (ESS)

	Weight (lbs)
IOC	4,689
Growth	9,377

PMAD

	Weight (lbs)	Volume (ft ³)
ESS/PMAD Module	210	1.34
Habitat Module	362	6.70
Logistics Module	221	3.53
Laboratory Module	372	6.56
Comman/Control Module	1,978	23.64

nominally edge-on to the flight path. Low drag was the objective in selecting this particular flight path/configuration and it results in an array that is approximately twice as large as an array which is oriented to the sun. This orientation results in an array performance that is variable during an orbit, i.e., array is edge-on to the sun when it first appears in the light and progresses to a point such that it is perpendicular to the sun and then begins to decrease again. This variable output will mean that the PMAD must be capable of managing the array and the energy storage system outputs in load sharing modes during portions of the orbit. The array output vs. orbit position is shown in figure 3.4.3.6.2-2.

As in the other configurations, the arrays will require a box, wireguides, blanket, etc. (see figure 3.3.3.6.2-2). On the first launch 10,000 ft² of array will be installed and will provide 25 KW for station use during buildup. The array will be attached to the truss at periodic locations and a mechanism will be provided to deploy and retract the array when required.

3.4.3.6.3 Technical Evaluation

The following items should be considered for the "T" configuration:

1. The array for the "T" configuration will be at least twice as large as for a solar oriented array.
2. The ESS will be larger by approximately 25% due to the varying power output of the solar array. This necessitates load sharing with the fuel cell during that portion of the orbit when the power output from the solar array is less than what is required by the station. This also means that the electrolysis unit must accommodate power input that varies from zero to almost twice the normal input.
3. The PMAD will have to control these load sharing activities.

4. The drag for this station will be minimized and therefore, the reduction of propellant cost will be offset by the increase in power system complexity and size.

5. The station could operate in a stable altitude mode with total loss of control and the solar array would continue to supply power.

6. The array will be attached to the support truss.

7. The power transmission lines will need to be 280 feet long to go from the ESS/PMAD modules to the station modules.

8. The ESS, composed of RFC's, does not comply with the man-rated redundancy specification until the third ESS/PMAD module is installed.

3.4.4 Operation Accommodation Evaluation

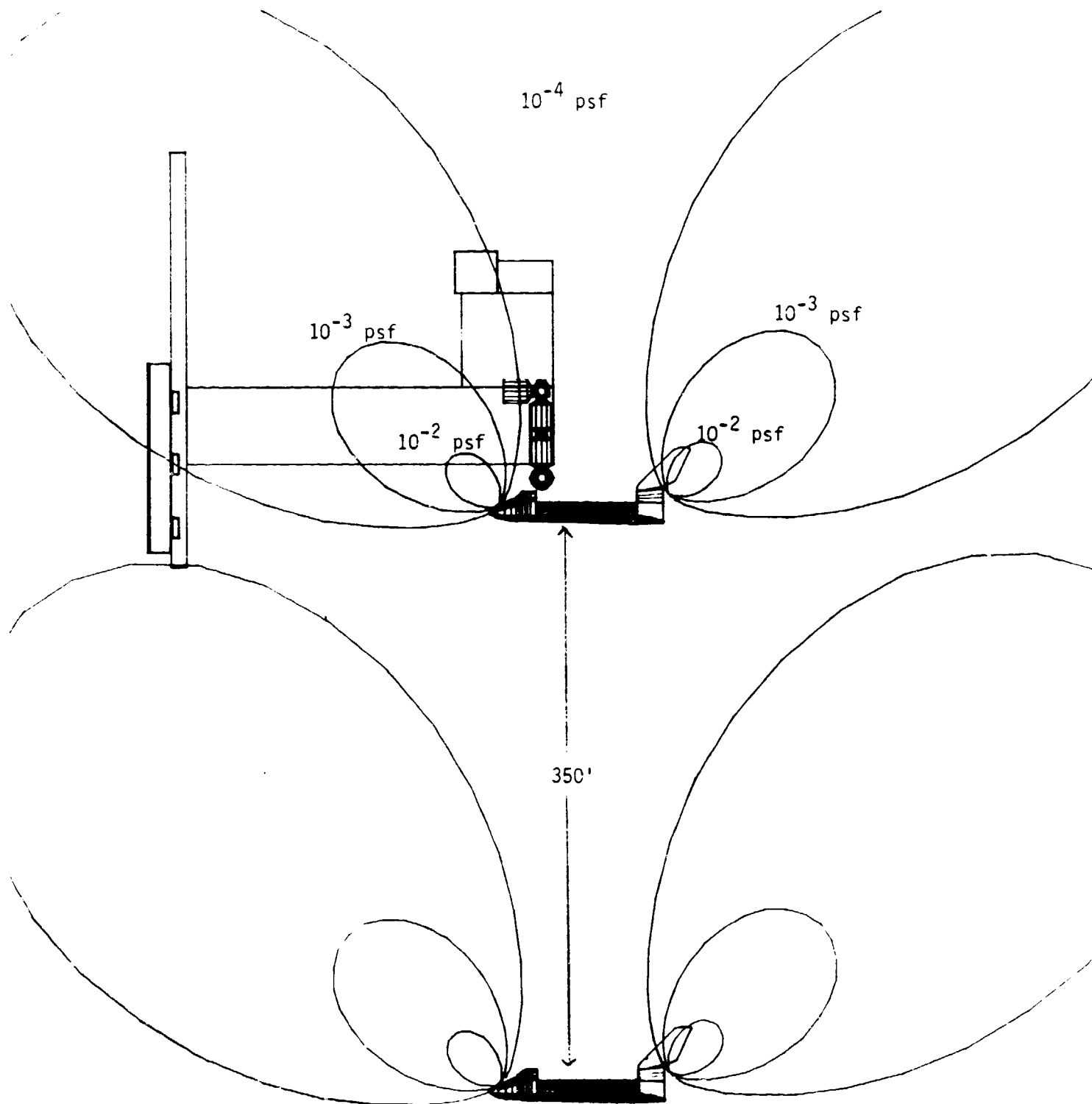
3.4.4.1 Configuration Design Considerations

3.4.4.1.1 Separation from the Space Station

The big "T" IOC shown in figure 3.2.4.1-1 illustrates two docking ports located side by side (similar to the delta IOC) on the positive velocity vector in an LVLH system. This situation lends itself to the +Vbar separation and return scenarios presented in section 4.11.

The location of the solar arrays on the T configuration may present a problem during the proposed separation and return. The first major burn of the +Vbar separation sequence is a 1.0 fps radial burn performed approximately 10 minutes after initiation of the sequence. The burn is performed about 100 feet in front of and 80 feet above the docking port. The plume flowfield resulting from this radial burn may generate excessive torques due to the large surface area of the arrays. Figure 3.4.4.1-1 illustrates the situation of the Orbiter separating from the T. The figure shows the VRCS plume flowfield that would result from the initial burn of the sequence as it moves away from the port.

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Note: Figure assumes one nose and two tail VRCS jets added to Orbiter canted 45° from vertical.

Figure 3.4.4.1-1. VRCS Plume Dynamic Pressure Contours ("T" Configuration)

3.4.4.1.2 Return to the Space Station

The velocity vector return profile described in section 4.11 represents an adequate approach trajectory for a vehicular rendezvous with the big "T" configuration. The procedure should present no major problems during the return. However, concern may again arise regarding two vehicles docked simultaneously to the station and plume impingement during the approach. These problems will be discussed briefly in section 4.11 and should be referred to here.

3.4.4.2 RMS Reach Capability

An integral subsystem of the Space Station will be one or more manipulators remotely operated and used to perform a variety of operations. Some of the more critical requirements of a station manipulator will be station assembly, module removal, OMV/OTV berthing in the hangar area, deployment of the OMV/OTV from the hangar area, as an aid to OMV, OTV, and satellite servicing, and possibly as an aid to Orbiter/station berthing. The analysis conducted in support of this document emphasized the use of the current Shuttle RMS to the maximum extent possible for assembly of the big "T" concept. A "special" station manipulator was considered only for those operations which exceeded the reach capability of the Shuttle RMS.

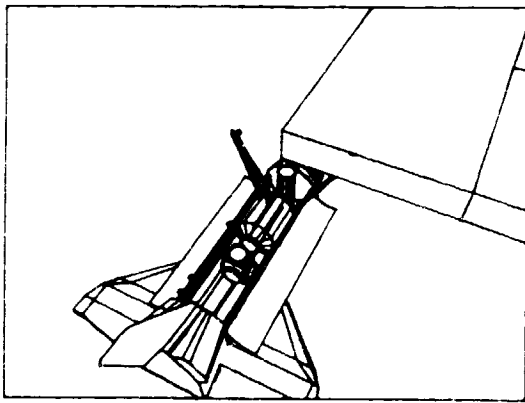
The RMS/station manipulator analysis was performed using the RMS Desk Top Planning (RPS) developed for RMS mission planning activities and used to define RMS payload handling capabilities and procedures for STS missions. The program was updated and modified to include the big "T" configuration as well as a generalized manipulator in the sense that the length of the manipulator booms can be varied to accommodate larger reach envelopes than the current RMS. The number of active joints can be reduced and the booms shortened so

that a Handling and Position Aid (HPA) type of mechanism can also be accurately simulated.

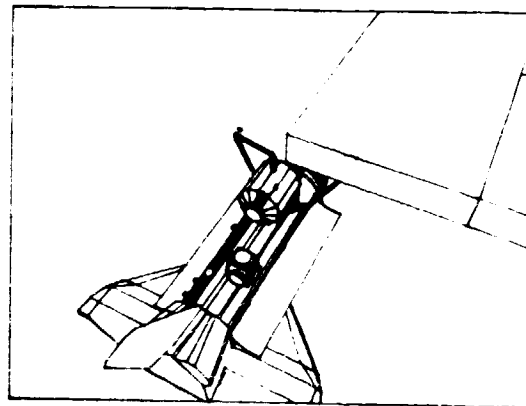
The manipulator analysis included herein, is based on a kinematic model of the RMS in that no rigid or flexible body dynamics are included. This limitation, however, does not invalidate the feasibility of using the RMS for station assembly since all modules handled are within the weight and inertia limits verified for standard RMS operations. The study results are based on the current RMS control algorithms and software and verify the reach capability as well as the maneuver path for both the RMS and the station manipulator. The simulation also checks for singularities and joint reach limits. In summary, all maneuvers studied for the big "T" configuration assembly sequence should be valid with the exception of possible crew visibility constraints. RMS operator eye-point and CCTV views can also be generated using the RPS simulation, and these results will be reported in future documentation. In performing the kinematic analysis to assess the RMS capability to remove station modules from the Orbiter payload bay and assemble the station, the following assumptions were used.

1. Truss structure is assembled prior to module deployment
2. Port and starboard RMS's are available
3. Once the C/C module and an interface module are attached to the truss structure, all remaining construction using the Orbiter RMS's will be accomplished with the Orbiter firmly docked to the Space Station.
4. Grapple fixture location and orientation are identical on all modules of the same type.
5. Payload bay locations consider only RMS reach capability and not Orbiter c.g. restrictions.

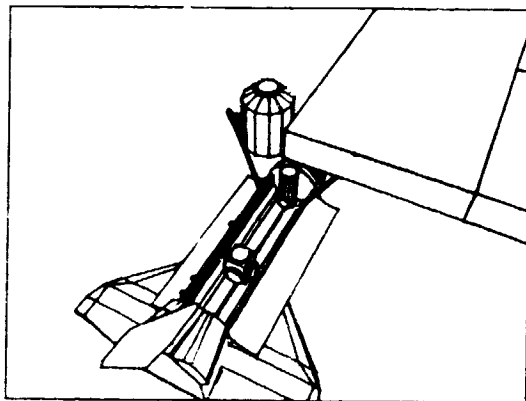
Figures 3.4.4.2-1 through 3.4.4.2-9 illustrate an assembly sequence for the IOC version of the big "T" configuration. Each figure represents a "snapshot" of the entire maneuver that was performed on the RPS simulation to verify the RMS reach capability and that the entire maneuver path was free of RMS singularities and that reach limits were not encountered. Each figure label reads as follows:



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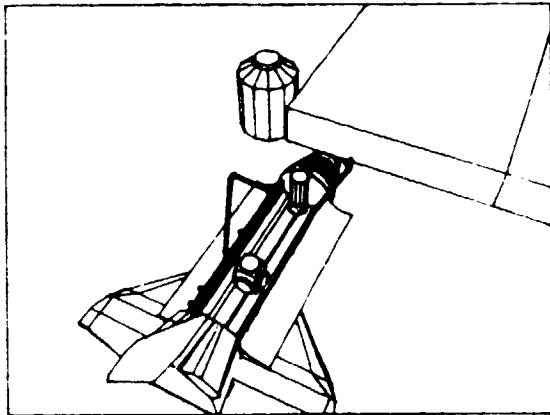


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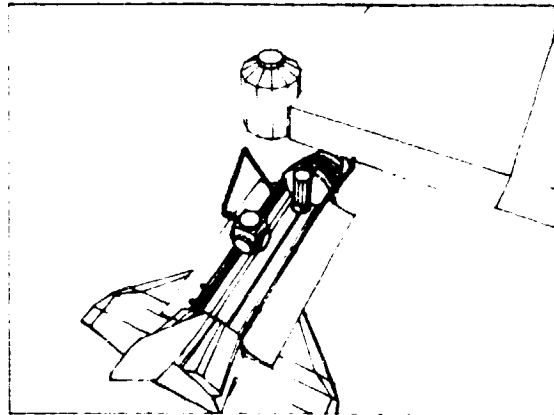
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Figure 3.4.4.2-1. Big T Assembly - C/C Module

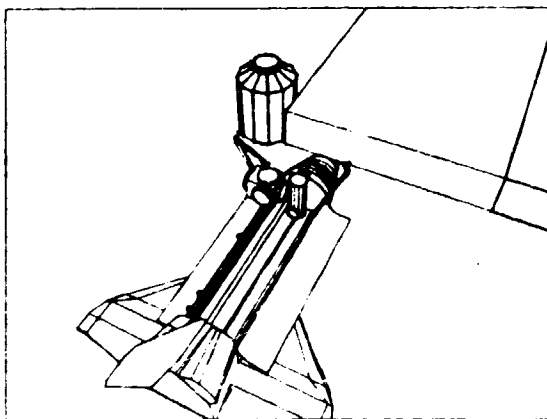
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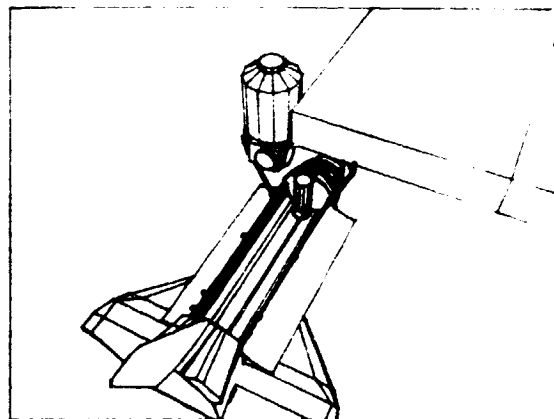
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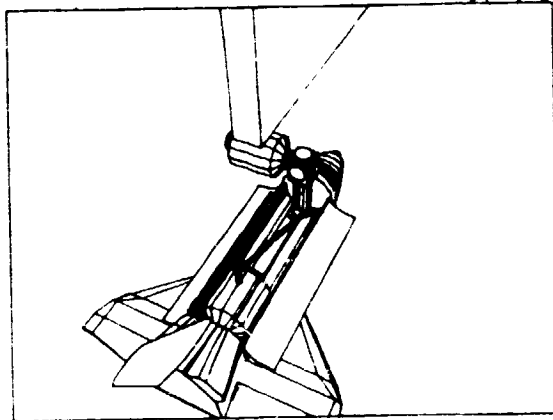
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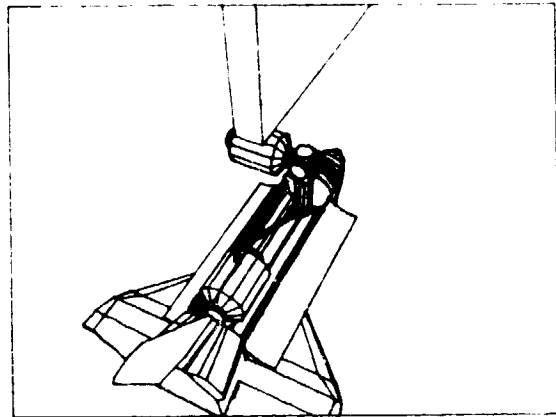
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Figure 3.4.4.2-2. Big T Assembly - Interface Module

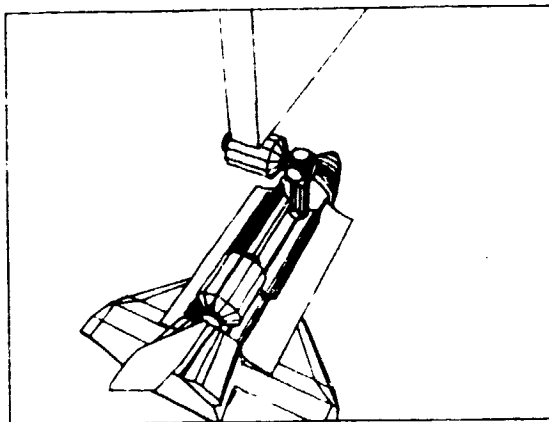
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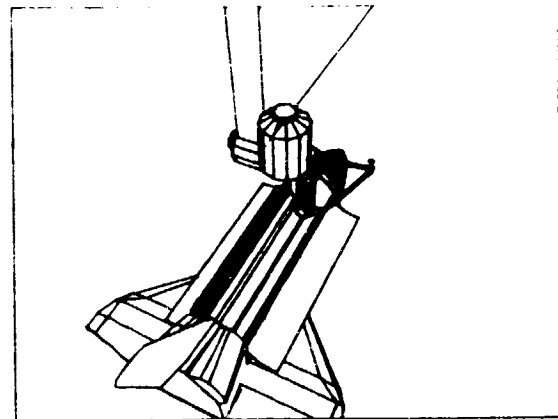
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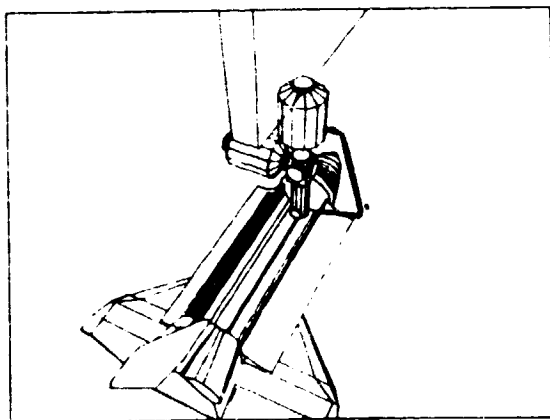
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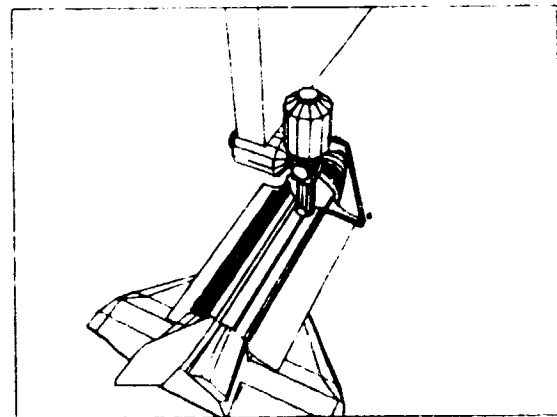
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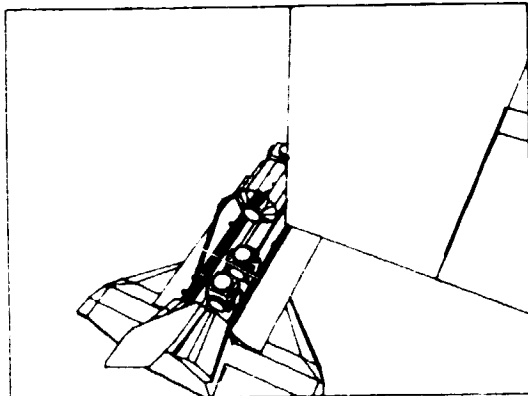
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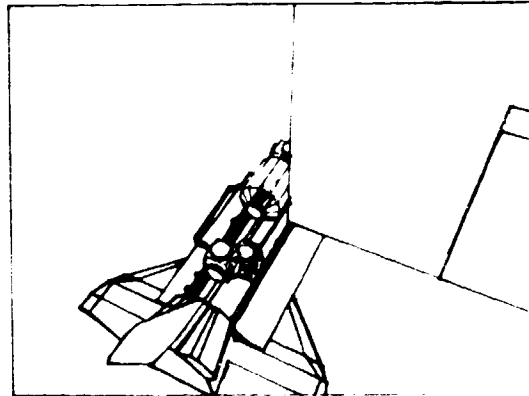
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Figure 3.4.4.2-3. Big T Assembly - Lab Module

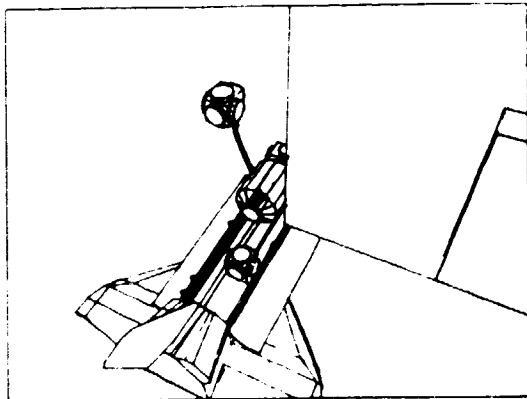
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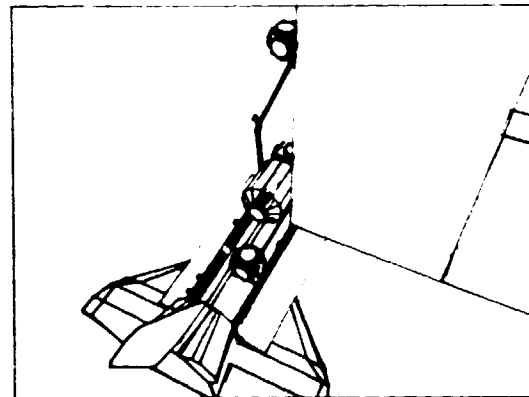
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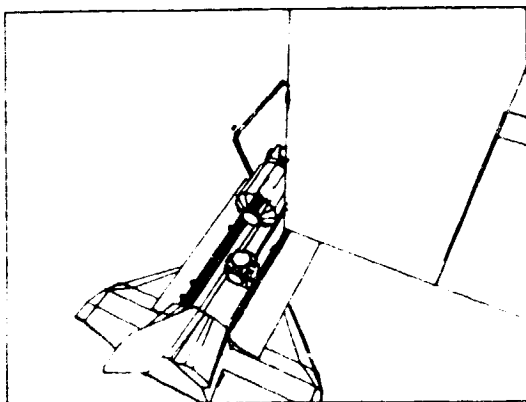
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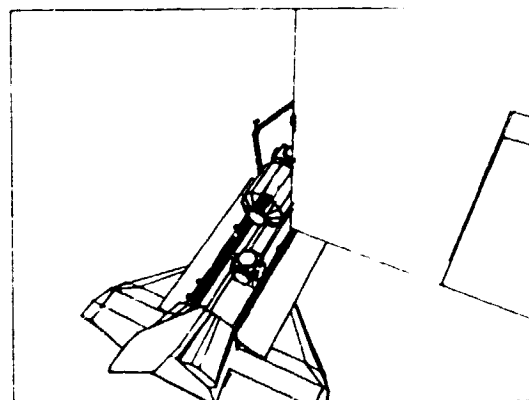
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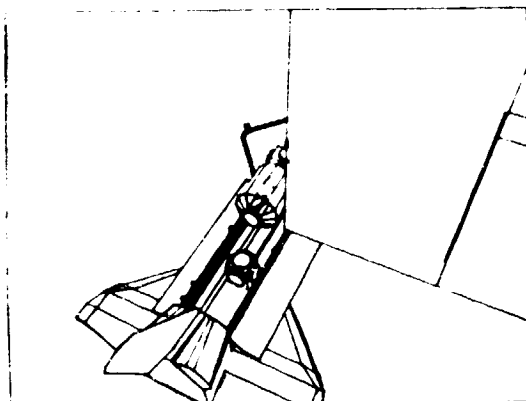
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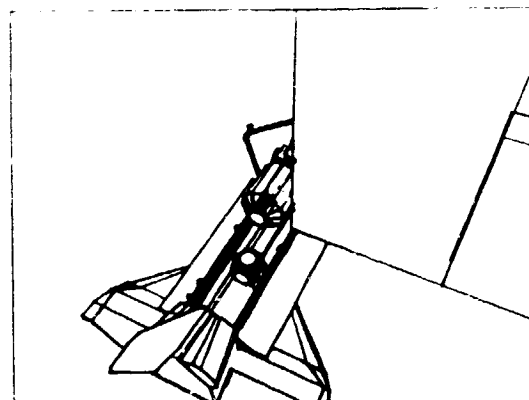
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T-F3R-6



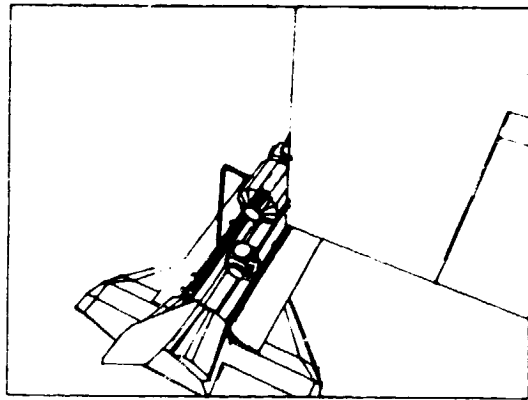
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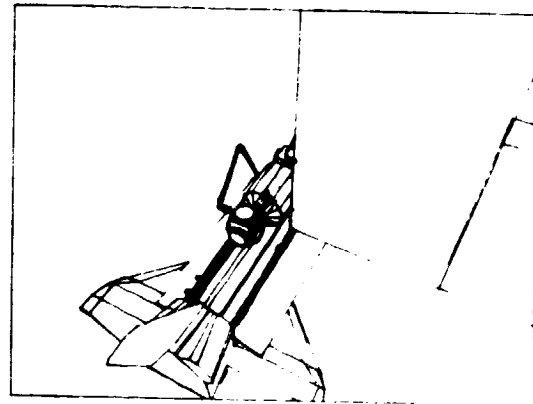
T-F3R-8

Figure 3.4.4.2-4. Big T Assembly - Second Interface Module

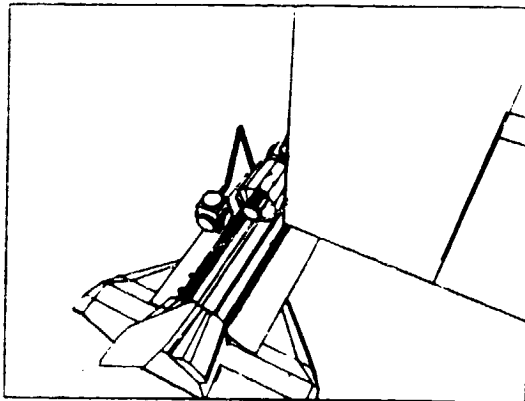
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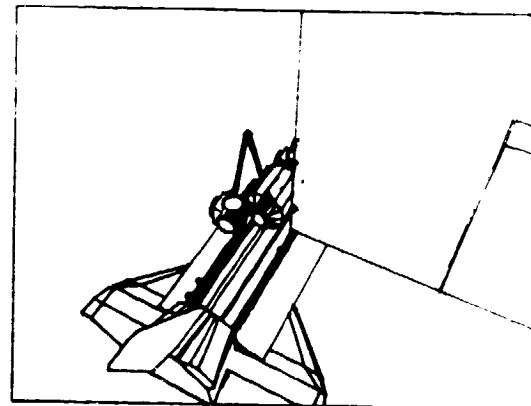
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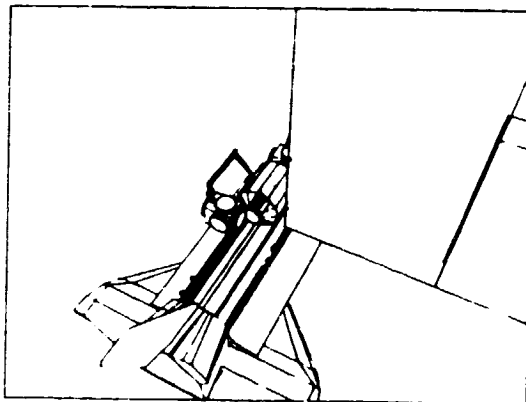
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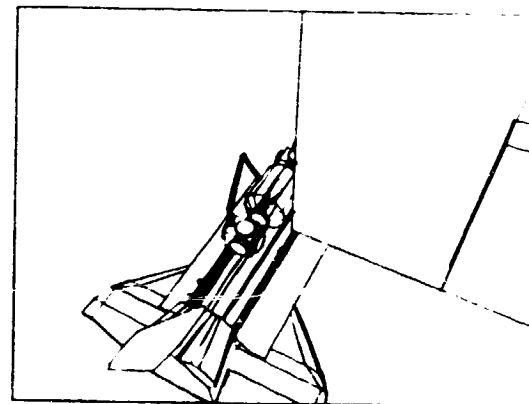
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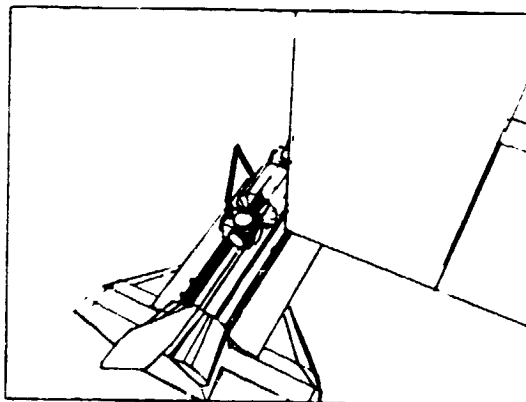
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T-F3B-5



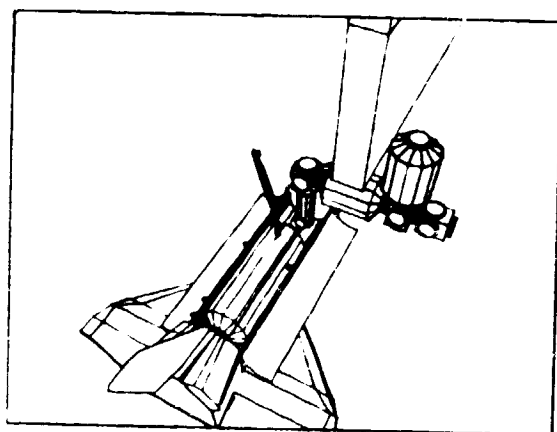
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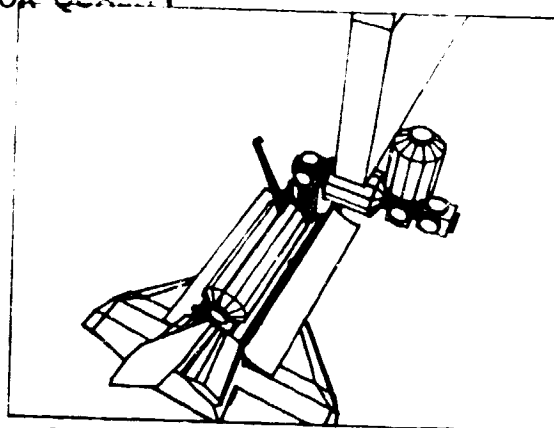
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Figure 3.4.4.2-5. Big T Assembly - Third Interface Module

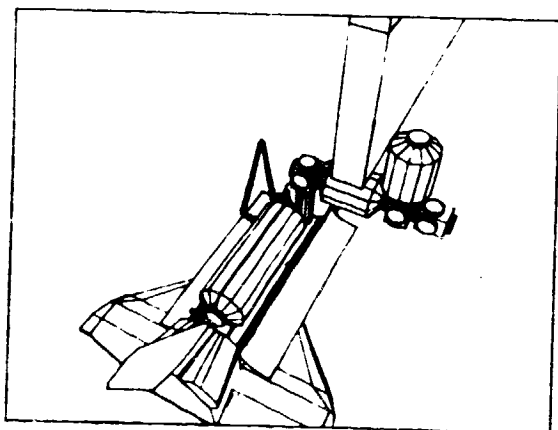
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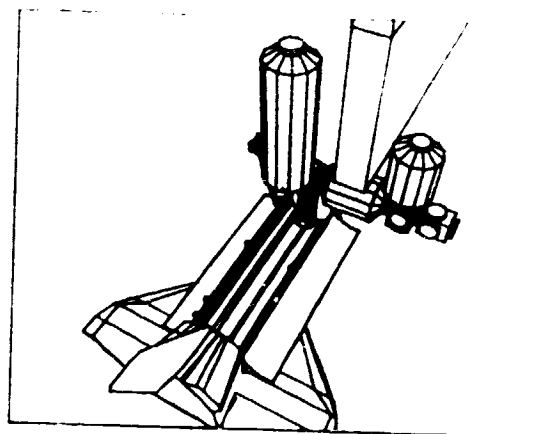
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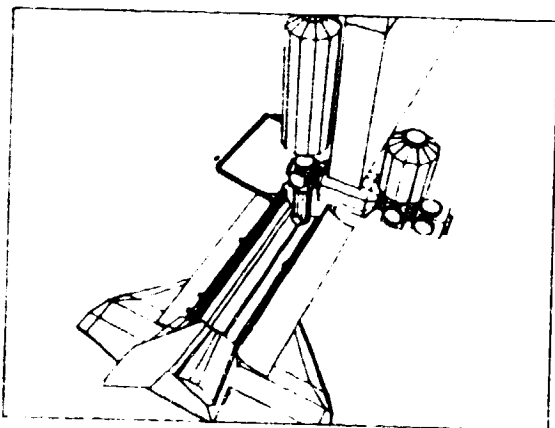
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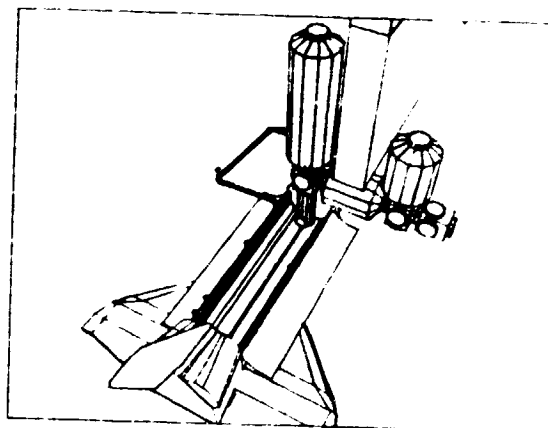
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T-F4-4

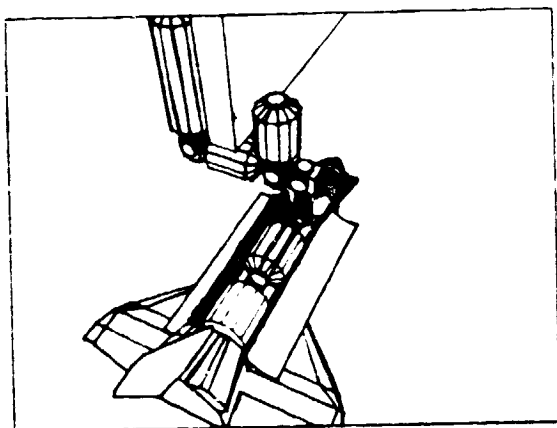


T-F4-5

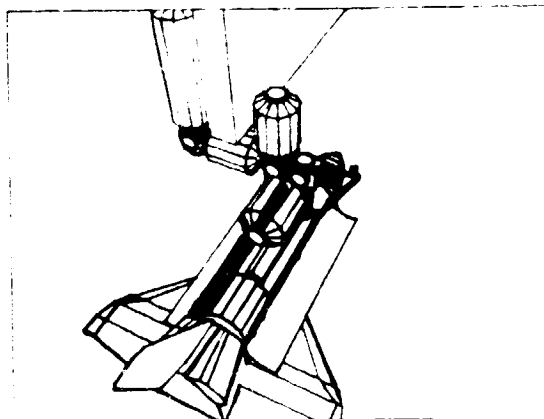


T-F4-6

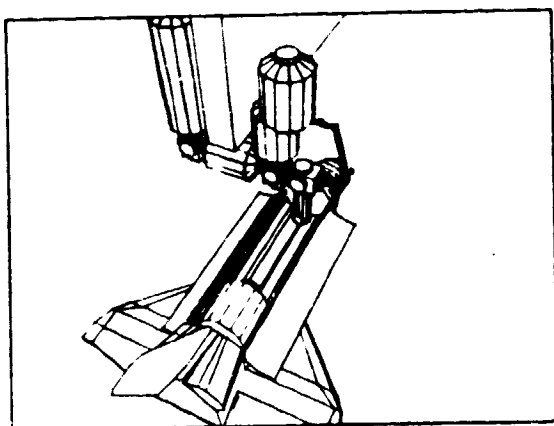
Figure 3.4.4.2-6. Big T Assembly - Habitat Module



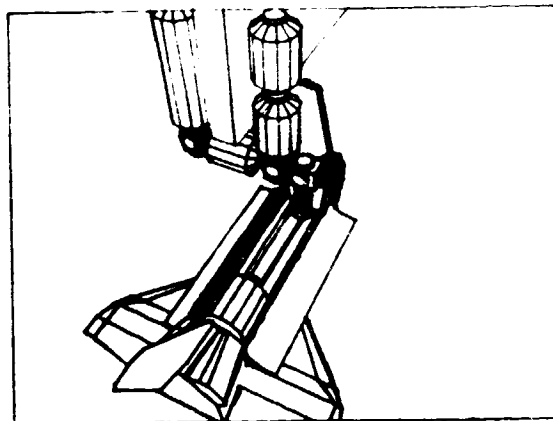
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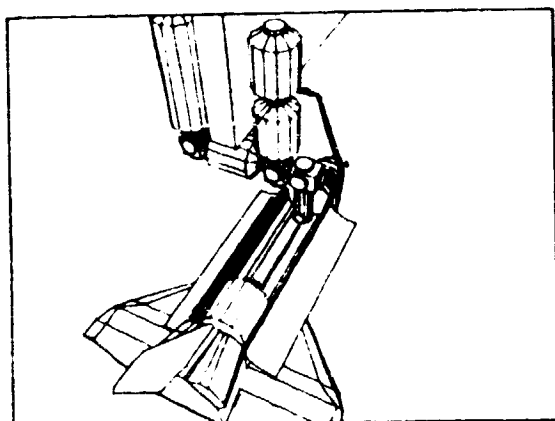
T-F5A-2



T-F5A-3



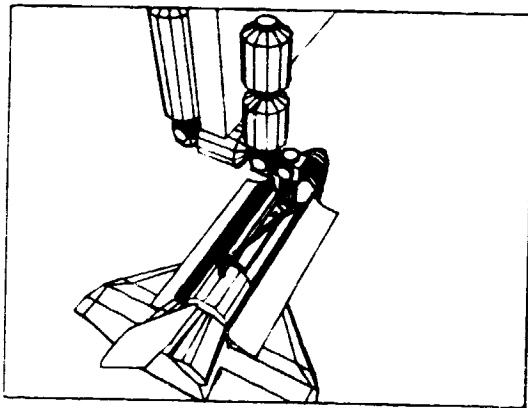
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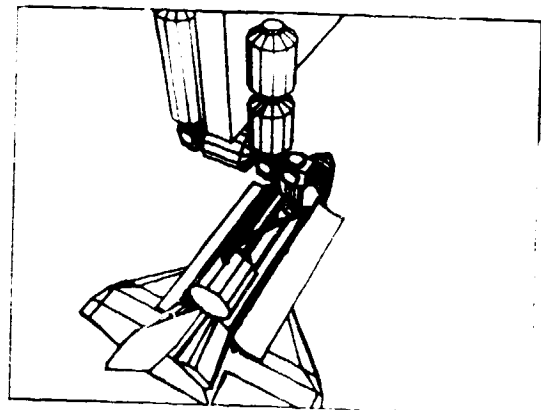
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Figure 3.4.4.2-7. Big T Assembly - Second Lab Module

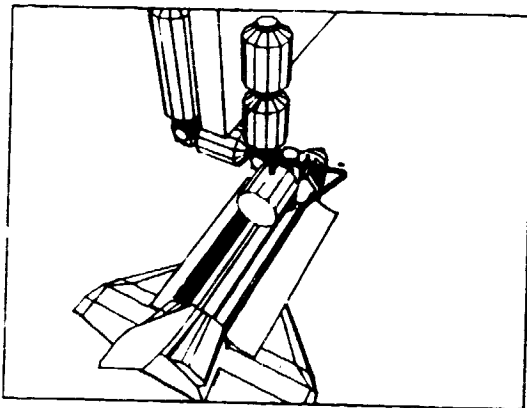
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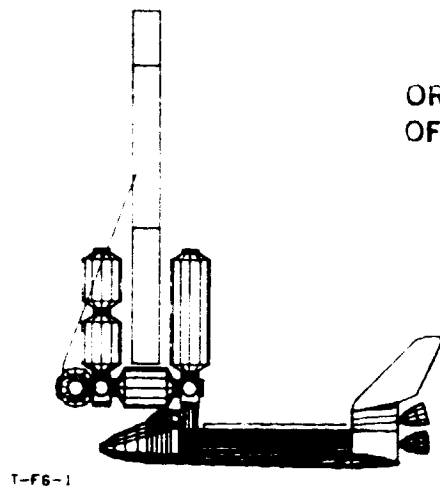
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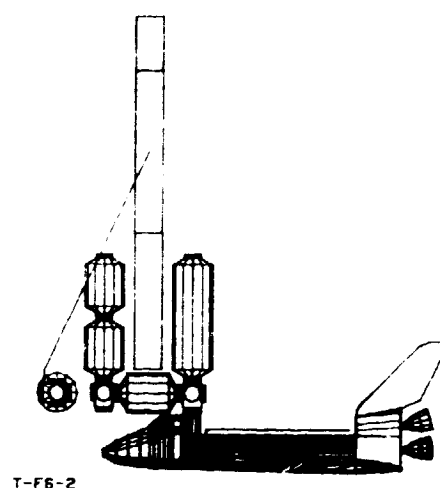
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Figure 3.4.4.2-8. Big T Assembly - Logistics Module

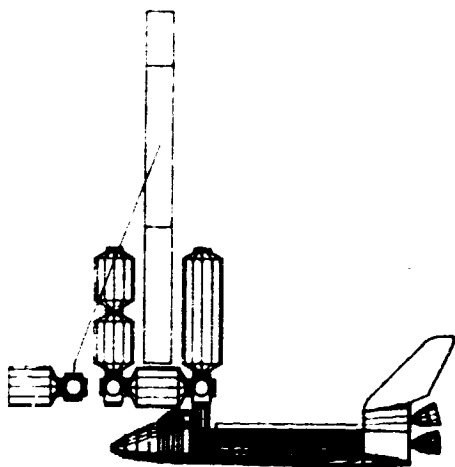
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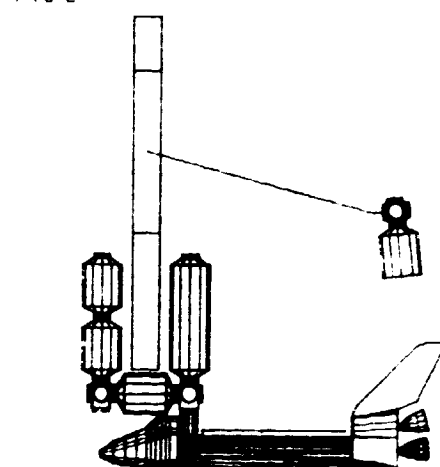
T-F6-1



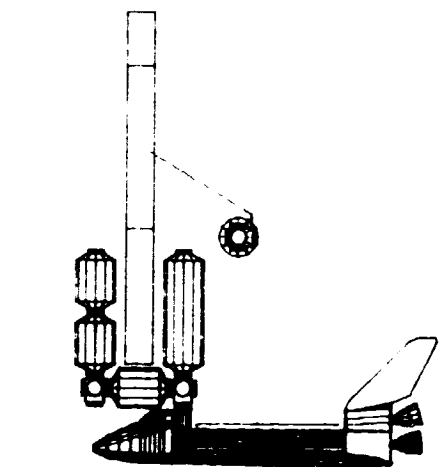
T-F6-2



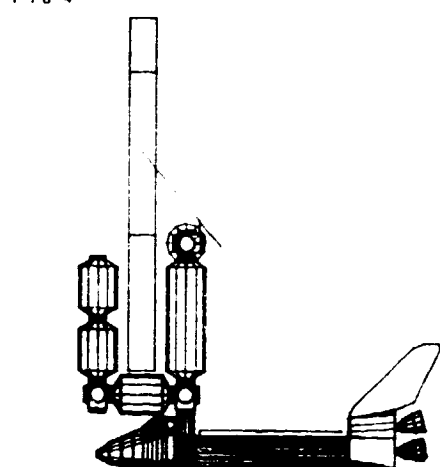
T-F6-3



T-F6-4

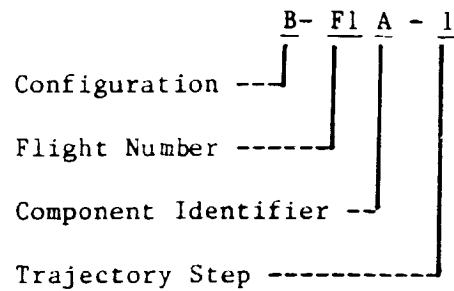


T-F6-5



T-F6-6

Figure 3.4.4.2-9. Big T Assembly - Logistics Module
Final Placement Using Station Manipulator



The component identifier appears only in labels where more than one component to be assembled is manifested in the cargo bay for that flight. The trajectory step refers to the sequenced "snapshots" of the RMS configurations during a specific maneuver.

Flight 1 carries to orbit the truss structure as well as the C/C module and one IM. The RMS assembly sequence shown in figures 3.4.4.2-1 and 3.4.4.2-2 assumes that the truss structure is deployed and that a grapple fixture is located at the required position on that structure for handling with the starboard RMS. The truss structure is grappled with the starboard RMS and positioned on the starboard side of the Orbiter as shown to allow adequate clearance when maneuvering the remaining modules with the port RMS. The C/C module is removed from the bay and positioned correctly with respect to the truss. The details of how it is attached to the truss are not considered in this part of the analysis. The combined structure is then repositioned with the starboard RMS to allow the port RMS to grapple the interface module and berth it to the C/C module. This concludes the RMS procedures for flight one. All following flights assume the Orbiter is rigidly docked to the Space Station.

Figure 3.4.4.2-3 shows the Flight 2 assembly sequence once the Orbiter is docked to the IM. The starboard RMS is required to maneuver the lab module from the Orbiter bay to its docked position on the interface module as shown

in the steps of the figure.

Figure 3.4.4.2-4 and 3.4.4.2-5 represent Flight 3 in which an interface module and the Station Manipulator (SM) are brought up. One IM is placed on the C/C module, while the second is "stored" on the IM assembly from Flight 1. The port RMS can accomplish the Flight 3 scenario alone.

Flight 4 docks the habitability module to the IM as shown in figure 3.4.4.2-6 using the port RMS.

Flight 5 which is illustrated in figures 3.4.4.2-7 and 3.4.4.2-8 is the last flight in which module assembly can be accomplished using only the Orbiter RMS capability. The second Lab module is docked to the Lab module already in place, using the starboard RMS. The logistics module is then docked to the third interface module, taken up on Flight 3, where it will stay until the "Station Manipulator (SM) is put in place on Flight 6.

Flight 6 will require that the SM be placed on the truss structure as shown in figure 3.4.4.2-9 to allow completion of the module assembly. With upper and lower arm boom lengths of 50 feet and 60 feet respectively, the logistics module and interface module can be moved from the intermediate location at which they were placed on Flight 5 to their final location. The remaining interface module, tunnel, and OMV hangar can be maneuvered into position using the SM in conjunction with the Orbiter RMS on Flight 7.

3.4.5 Safety Accommodations Evaluation

The safety accommodations provided for the IOC Phase (Phase I) were used for the basic concept evaluation since this was considered the most critical with respect to crew safety. The growth phase volume available increases the time

of reaction to a leak to approximately one hour (see section 3.4.5.5).

Otherwise, the comments are applicable to both Phase I and Phase IV.

3.4.5.1 General

The big "T" configuration would appear to satisfy the gross requirements for crew safety if it can be assumed that the detailed design requirements and the operational constraints presently stated in Space Station Configuration Books 3 and 6 are imposed.

3.4.5.2 All Habitable Modules (Habitat, Laboratories, Interface and C/C) Egress Capability

Dual egress paths from each module are incorporated. A backup Command and Control facility will be in the Habitat Module.

3.4.5.2.1 Logistics Module

Book 3 Systems Requirements and Characteristics specifically exempts the logistics module from the "two or more entry/egress paths." The logistics module has only one egress path, the risk to a crewmember occupying this volume during the occurrence of an accident forcing evacuation of the volume could probably be reduced to an acceptable level by proper location of equipment, adequate materials control, elimination of potential ignition sources, and maintenance of adequate traverse clearance during operations in the module.

3.4.5.3 Enclosure of High-Pressure or Hazardous Fluid Tanks

The logistics module will be divided into a pressurized section and an unpressurized section. High pressure and hazardous fluids will be transported

in the unpressurized section to avoid the possibility of fluids propagating into other modules or cause overpressurization of one or more modules. The separation distance of various tanks has not been defined.

3.4.5.4 Isolation of Modules after Accident Occurrence

One problem that arises from the provision of dual egress routes from a habitable module is the complexity of the process of sealing off that module after such things as a spill of a toxic fluid. This suggests the desirability of a self-contained environmental control circulation system for modules such as the laboratories to minimize the potential for cross-contamination of modules while the hatches at each end of the contaminated module are being closed.

3.4.5.5 Reaction Time after Occurrence of a Leak

The Safety Division position, with respect to hatch management, is that all hatches should be normally open to create ease of transit from module to module, reduce the wear on hatch mechanisms, prevent hatch opening difficulties because of small pressure differentials, and maintain the maximum volume for bleed down in case of a leak. Of these reasons, the last is probably most significant, considering the large number of sealing surfaces and the increased potential for a leak. In the IOC configuration of the big "T", a rough calculation of the time to react to the occurrence of a leak equivalent to a one-inch diameter hole would be about 30 minutes, assuming a 95 percent efficient orifice, an occupancy of 25% solids in the station, and a reduction of pressure from 14 to 9.1 psia. If a leak detector sufficiently accurate to determine the module containing the leak is available, this should allow adequate time to react to the occurrence by evacuating and sealing off the affected module.

3.4.5.6 EVA Operations

The antenna locations are apparently such that radiation hazards to EVA crewmembers are minimal, but some Reaction Control System (RCS) package locations may require thruster deactivation during EVA. The system geometry should allow ready design and implementation of adequate EVA traverse and work station retention mechanisms.

3.4.5.7 Repair and Reactivation of Modules after an Accident

Adequate airlock provisions are provided to allow Intervehicular Activity (IVA) suited reentry into a module that has been isolated because of an accident to perform necessary repair or reconfiguration to permit continued use of the module.

3.4.5.8 Multiple Orbiter Docking Ports

The ability to dock with and access the Orbiter from various volumes of the Space Station is acceptable.

3.4.6 Cost Evaluation

3.4.6.1 Groundrules and Assumptions

The following groundrules and assumptions were used in the cost analysis for the big "T" configuration:

- o The Space Station Cost Model (SSCM) developed by Planning Research Corporation (PRC) was used to develop hardware and system level costs.
- o The concept was treated as one work package.
- o The IOC configuration only was costed.
- o No learning was assumed.
- o No explicit reserve was included.

- o No STS flight costs were included
- o Subsystem costs were allocated to the modules on the basis of weight.
- o Costs are expressed in millions of 1984 constant year dollars. Since SSCM outputs costs in 1982\$, the inflation adjustment was made using the NASA R&D inflation index (1.175 for 1982 to 1984 dollars).
- o Program level costs (including fee) were included using the Code B factors.
- o Complexity factors considered to be 1.0 except the following:
 - o Closed loop ECLS was costed using the open loop ECLS CER with 1.6 complexity factor. Factor based on CDG trade study.
 - o Berthing and docking adapter used a 0.8 complexity factor and used the ASTP adapter as an analogy.
 - o Complexity factor of 0.6 used for fuel cell based on JSC analysis.
 - o GSE complexity factor of 0.8 was used, based on CDG cost estimate.

3.4.6.2 Presentation of Results

Figure 3.4.6-1 presents the results of the SSCM for the big "T" approach. The model computes the DDT&E and the first unit costs. The costs shown are for one of each Space Station module or element (i.e., hab module, boom array, etc.) Therefore, figure 3.4.6-1 does not show the total cost of the station. Figure 3.4.6-2 presents the DDT&E and First Unit Costs after being spread to the different modules. The three parts to this figure present cost spreads by module for DDT&E, Production, and total costs. As with the previous figure, the costs shown for the production phase are for the first unit of each of the modules.

Figure 3.4.6-3 presents the summary of the costs by quantities and types of modules that comprise the IOC configuration. The first two cost columns recap

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FIGURE 3.4.6-1

SPACE STATION COST MODEL

FIG 1 CONCEPT

INFL FACTOR: 1.175 FY84 \$\$ (IN MILLIONS)

SUBSYSTEM	WEIGHT	D&D CMPLX	D&D COST	EQUIV UNITS	TOTAL PROG COST	TOTAL COST
STRUCTURE			633.4		555.6	1189.0
..CORE	1896	1.00	60.7	4.00	52.1	112.8
..CYLINDER	2641	1.00	73.2	13.00	206.0	279.2
..ENDCAP	931	1.00	40.6	10.00	85.4	126.0
..TUNNEL	1090	1.00	44.4	1.00	9.4	53.8
..TRUSS	9550	1.00	79.0	1.00	26.0	105.0
..SECOND'Y	16069	1.00	214.6	1.32	47.5	262.1
..DOCK ADAPT	600	0.80	10.3	12.00	15.8	26.1
..BERTH ADAPT	600	0.80	10.3	26.00	34.2	44.4
..CMPLX MECH	2512	1.00	78.2	2.80	60.5	138.7
..MECH'ISMS	955	1.00	22.1	4.74	18.9	40.9
THERMAL	5701	1.00	105.2	4.97	178.0	283.2
6 N & C			159.0		139.6	298.6
..ELECTRONICS	78	1.00	116.8	6.78	88.6	205.4
..CMG	650	1.00	40.3	6.00	45.0	85.2
..MAG TORQ	120	1.00	2.0	3.00	6.0	8.0
RCS	1223	1.00	8.2	2.22	4.7	12.9
POWER			94.2		359.9	454.1
..SOLAR (KW)	59.5	1.00	23.4	6.00	255.4	278.8
..BATT	0	1.00	0.0	1.00	0.0	0.0
..DIST, REG	208	1.00	13.7	12.89	14.5	28.2
..FUEL CELL	1887	0.60	57.1	6.00	90.0	147.1
COMM & DATA	3212	1.00	197.2	2.96	109.4	306.6
ECLSS	5335	1.60	249.5	2.72	171.1	420.7
CREW PROV	1808	1.00	39.2	3.44	26.7	65.9
THRUPUT	0	0.00	0.0	0.00	0.0	0.0
SUBTOTAL			1486.1		1544.9	3031.0
SYS TEST HDW		1.00	1272.7		0.0	1272.7
INST, ASSY, & C/O		1.00	175.1	1.59	169.4	344.5
SYS TEST OPNS		1.00	640.1		0.0	640.1
GR SPT EQMT		0.80	491.7		0.0	491.7
SYS ENGR & INT		1.00	335.2	1.59	132.6	468.1
PROG MGMT		1.00	250.0	1.59	199.2	449.2
TOTAL			4650.8		2046.4	6697.3
PROG SPT (14%)			651.1		286.5	937.6
MGT & INT (5%)			265.1		116.6	381.7
FEE (8%)			445.4		196.0	641.3
TOTAL PROGRAM			6012.4		2645.6	8657.9

FIG. 3.4.6-2A

COST SUMMARY- BIG T CONCEPT

ORION
DEVELOPMENT

DDTE PHASE

SUBSYSTEM	SUBSYS TOTALS	COST (MILLIONS OF 84 \$)								
		C/C	MAB	LAB	IM1	A/L	TRS	OMV	TML	LOG
STRUCTURE	633	69	111	63	78	56	129	40	44	43
..PRESSURIZED	219	24	43	24	30	30	0	0	44	24
..SECONDARY	294	43	65	34	17	17	79	21	0	18
..DOCK & BERTH	21	1	1	5	6	6	0	0	0	1
..MECH'ISMS	100	1	1	1	24	3	50	19	0	1
THERMAL	105	24	13	57	0	0	11	0	0	0
G N & C	159	11	2	2	68	77	0	0	0	0
..ELECTRONICS	117	9	2	2	55	50	0	0	0	0
..CMS	40	0	0	0	13	27	0	0	0	0
..MAG TORQUERS	2	2	0	0	0	0	0	0	0	0
RCS	8	8	0	0	0	0	0	0	0	0
POWER	94	5	3	3	0	0	80	0	0	2
..SOLAR ARRAY	23	0	0	0	0	0	23	0	0	0
..BATTERIES	0	0	0	0	0	0	0	0	0	0
..COND & REG	14	5	3	3	0	0	0	0	0	2
..FUEL CELL	57	0	0	0	0	0	57	0	0	0
COMM & DATA	198	85	23	17	3	3	62	4	0	1
ECLSS	250	92	77	29	0	0	0	0	0	52
CREW PROV	39	3	35	1	0	0	0	0	0	0
THROUGHPUT	0	0	0	0	0	0	0	0	0	0
<hr/>										
SUBTOTAL	1486	297	263	172	149	136	283	44	44	98
<hr/>										
SYS TEST HDWE	1273	255	225	147	127	116	242	38	38	84
INT, ASSY, & C/O	175	35	31	20	18	16	33	5	5	12
SYS TEST OPN	640	128	113	74	64	59	122	19	19	42
GR SPT EQMT	492	98	87	57	49	45	93	15	15	32
SYS ENGR & INT	335	67	59	39	34	31	64	10	10	22
PROG MGMT	250	50	44	29	25	23	48	7	7	17
<hr/>										
TOTAL	4651	930	824	537	465	425	884	139	139	307
<hr/>										
PROG SPT (14%)	651	130	115	75	65	60	124	19	19	43
MGT & INT (5%)	265	53	47	31	27	24	50	8	8	18
FEE (8%)	445	89	79	51	45	41	85	13	13	29
<hr/>										
TOTAL	6012	1202	1065	694	602	550	1143	180	180	397

FIG. 3.4.6-2B

COST SUMMARY- BIG T CONCEPT

FIRST UNIT - PROD PHASE

SUBSYSTEM	SUBSYS TOTALS	COST (MILLIONS OF 84 \$)								
		C/C	HAB	LAB	IN1	A/L	TRS	DMV	TNL	LOG
STRUCTURE	426	61	113	63	35	31	47	10	9	56
..PRESSURIZED	278	49	96	49	13	13	0	0	9	49
..SECONDARY	62	7	11	6	3	3	26	4	0	3
..DOCK & BERTH	29	3	3	5	8	8	0	0	0	3
..MECH'ISMS	57	3	3	3	11	8	21	7	0	2
THERMAL	146	18	16	31	1	0	79	0	0	1
G N & C	74	8	1	1	33	32	0	0	0	0
..ELECTRONICS	46	2	1	1	25	17	0	0	0	0
..CMG	23	0	0	0	8	15	0	0	0	0
..MAG TORQUERS	6	6	0	0	0	0	0	0	0	0
RCS	2	2	0	0	0	0	0	0	0	0
POWER	356	3	3	3	0	0	345	0	0	2
..SOLAR ARRAY	255	0	0	0	0	0	255	0	0	0
..BATTERIES	0	0	0	0	0	0	0	0	0	0
..COND & REG	11	3	3	3	0	0	0	0	0	0
..FUEL CELL	90	0	0	0	0	0	90	0	0	2
COMM & DATA	95	40	14	12	1	2	21	4	0	1
ECLSS	147	52	48	24	0	0	0	0	0	23
CREW PROV	25	3	19	2	0	0	0	0	0	0
THROUGHPUT	0	0	0	0	0	0	0	0	0	0
SUBTOTAL	1271	187	211	136	70	65	493	14	9	83
SYS TEST HDWE	0	0	0	0	0	0	0	0	0	0
INT, ASSY, & C/O	140	21	23	15	8	7	54	2	1	9
SYS TEST OPN	0	0	0	0	0	0	0	0	0	0
GR SPT EQMT	0	0	0	0	0	0	0	0	0	0
SYS ENGR & INT	109	16	18	12	6	6	42	1	1	7
PROG MGMT	164	24	28	18	9	8	64	2	1	11
TOTAL	1684	248	283	180	93	86	653	18	12	110
PROG SPT (14%)	236	35	40	25	13	12	91	3	2	15
MGT & INT (5%)	96	14	16	10	5	5	37	1	1	6
FEE (8%)	161	24	27	17	9	8	63	2	1	11
TOTAL UNIT	2177	321	366	233	120	111	844	23	16	143

ORIGINAL
OF POOR QUALITY

FIG. 3.4.6-2C
COST SUMMARY- DELTA CONCEPT

DDTE + FIRST UNIT

SUBSYSTEM	SUBSYS TOTALS	COST (MILLIONS OF 84 \$)								
		C/C	HAB	LAB	IMI	A/L	TRS	DMV	TML	LOG
STRUCTURE	1059	130	223	126	113	88	177	50	54	99
..PRESSURIZED	497	72	140	72	43	43	0	0	54	72
..SECONDARY	356	50	76	40	20	20	105	24	0	20
..DOCK & BERTH	50	4	4	10	14	14	0	0	0	4
..MECH'ISMS	157	4	4	4	36	10	72	26	0	2
THERMAL	251	42	29	88	1	0	90	0	0	1
6 W & C	233	19	3	3	101	108	0	0	0	0
..ELECTRONICS	162	11	3	3	80	67	0	0	0	0
..CMG	63	0	0	0	21	42	0	0	0	0
..MAG TORQUERS	8	8	0	0	0	0	0	0	0	0
RCS	11	11	0	0	0	0	0	0	0	0
POWER	450	8	6	6	0	0	426	0	0	4
..SOLAR ARRAY	278	0	0	0	0	0	278	0	0	0
..BATTERIES	0	0	0	0	0	0	0	0	0	0
..COND & REG	25	8	6	6	0	0	0	0	0	4
..FUEL CELL	147	0	0	0	0	0	147	0	0	0
COMM & DATA	293	125	37	29	4	4	83	8	0	3
ECLSS	397	143	125	53	0	0	0	0	0	75
CREW PROV	64	6	54	3	0	0	0	0	0	0
THROUGHPUT	0	0	0	0	0	0	0	0	0	0
SUBTOTAL	2757	484	477	308	219	200	775	58	54	181
SYS TEST HDWE	1273	255	225	147	127	116	242	38	38	84
INT, ASSY, & C/O	315	56	54	35	25	23	87	7	6	21
SYS TEST OPN	640	128	113	74	64	59	122	19	19	42
GR SPT EQMT	492	98	87	57	49	45	93	15	15	32
SYS ENGR & INT	445	83	78	50	40	36	106	11	11	29
PROG MGMT	414	74	72	46	34	31	111	9	9	27
TOTAL	6334	1178	1107	717	558	511	1537	157	151	417
PROG SPT (14%)	887	165	155	100	78	71	215	22	21	58.42
MGT & INT (5%)	361	67	63	41	32	29	88	9	9	23.79
FEE (8%)	607	113	106	69	53	49	147	15	15	39.96
TOTAL	8189	1523	1431	927	722	660	1987	203	196	539

FIG. 3.4.6-3

ORIGINAL
OF PROJECT

BIG T CONFIGURATION

COST SUMMARY BY MODULE

QTY	MODULE	FY84\$\$ (IN MILLIONS)			
		DDT	UNIT	PROD	TOTAL
1	CMD & CNTRL	297	187	187	484
1	HAB MOD	263	214	214	477
2	LAB MOD	172	136	272	444
2	I/F MOD	149	70	140	289
2	A/L MOD	136	65	129	265
1	TRUSS	283	493	493	775
1	HANGAR	44	14	14	58
1	TUNNEL	44	9	9	54
1	LOG MOD	98	83	83	181
HDM SUBTOTAL		1486	1271	1542	2757
SYS TEST HDM		1273	0	0	1273
INT, ASSY, C/O		175	140	169	344
SYS TEST OPN		640	0	0	640
GR SPT EQMT		492	0	0	492
SYS ENG & INT		335	109	133	468
PROG MGMT		250	164	199	449
SYS TOTAL		4651	1684	2043	6693
PROG SPT		651	236	286	937
MGT & INT		265	96	116	382
FEE		445	161	196	641
PROG TOTAL		6012	2177	2641	8653

the totals found in figure 3.4.6-2 for DDT&E and Production (First Unit). The third cost column is the total production costs taking into account the quantities of each module or element. The final column is the total of the DDT&E and Production costs and is therefore, the total of the Space Station at IOC.

3.5 Summary Evaluation

The three Space Station configuration concepts presented met all the requirements set forth for this study. They do perform different functions better, depending upon their design concept purpose, but they all do reasonably well on the evaluation criteria that were imposed.

Some of the most important conclusions that can be drawn from this study concern those variables which do not appear to be strong discriminators between the three quite different configurations. The first of these is cost. Despite the attempt to minimize the total hardware requirements in the Building Block configuration, its cost to IOC, as shown in table 3.5-1, is actually higher than that of the Delta configuration, which includes an extensive truss structure absent from the Building Block configuration. Furthermore, even the addition of twice the solar array size to the "T" resulted in its cost being only 10% greater than that of the delta; a difference considered marginally significant at the level of the cost analysis. Second, the number of launches to reach the IOC state was found to be \pm one launch out of seven, again not significant at the level of the current manifesting study. The extensive vehicle dynamics study concluded that the propellant requirements differed, between the low-drag "T" and the relatively high drag Building Block, by less than 2,500 lbs. every 90 days, again not a significant discriminator; refer to table 3.5-2. The operations study also failed to find any of the configurations unacceptable from either an assembly or other operations standpoint; i.e., rendezvous and docking procedures are not significantly complicated by the inertial orientation of the Delta. Although the momentum storage requirements for the three configurations differ somewhat, that is also not considered a discriminating factor since all three are well within the state-of-the-art, and the cost impact of additional CMG units is minimal.

TABLE 3.5-1
COST COMPARISON

<u>CONFIGURATION</u>	<u>DDT&E</u>	<u>COST</u>	<u>IOC TOTAL</u>
BUILDING BLOCK	\$5.7 B		\$8.2 B
DELTA	\$5.7 B		\$8.0 B
"T"	\$6.0 B		\$8.7 B

TABLE 3.5-2

PROPELLANT REQUIREMENT SUMMARY

Pounds per 90 days, ISP = 220 sec

<u>PHASE</u>	<u>BUILDING BLOCK</u>	<u>CONFIGURATION</u>	
		<u>DELTA</u>	<u>"T"</u>
IOC	1500	1500	700
GROWTH	3000	2400	590

From a user accommodation standpoint, the use of a TEA flight mode for all three configurations was found to be highly desirable since it significantly reduces the need for RCS firings and hence, minimizes the periods of acceleration disturbances and sensor contamination. The basic earth orientation of the building block and "T" configurations is considered more desirable than the inertial orientation of the Delta for stellar and earth observations, but the capabilities of the Delta are found to be adequate; this difference is not a discriminator between the configurations.

The Building Block configuration provides the opportunity for solar region observations from a pressurized laboratory element, while the Delta provides this capability only from the command and control module and the "T" provides almost no such opportunity. However, there is no recognized requirement for such directly manned observations, and the placement of solar sensors on the solar array trusses of the "T" and Delta configurations provides excellent fields of view and minimizes the contamination encountered.

The most important discriminators from a user standpoint appear to be those associated with versatility and growth. The way in which the Building Block concept is configured in this study provides laboratory modules on the growth configuration in addition to those required. This provides more user pressurized volume than that contained in the Delta or "T" concept. However, the utilization of these modules is severely restricted by the difficulty of their removal for reconfiguration or repair. In addition, the extreme difficulty of increasing the power on the Building Block concept beyond that originally planned implies limitations to the uses of the station. The compact nature of the Building Block also limits the usefulness of the available berthing ports for payloads since clearance and access are limited.

The "T" and Delta configurations provide easy access to the berthing ports for payloads; and the exposed truss sections between the two "legs" of the module arrangement provide large versatile and accessible areas for not only earth viewing instruments, but unpressurized payloads of other types.

The separation of the solar and stellar viewing instruments on the solar array truss of the "T," and of the solar instruments on the Delta, from the modules is seen as a disadvantage from the standpoints of access by EVA or manipulators and for signal, command, etc., transmission. Thus, the "spread out" configurations of the "T" and Delta provide both advantages and inconveniences from a user standpoint.

The basic crew accommodations provided by each configuration are essentially the same since interior and module arrangement options were not included in the study. However, the external configuration was found to affect crew accommodation in the aspects of EVA operations and external viewing. In general, the larger Delta and "T" configurations were considered undesirable because of the long distances between the pressurized modules and equipment and experiments mounted on the solar arrays. These distances are considered significant because the length of time required to reach these destinations for equipment maintenance or experiment servicing was perceived to be substantial and because direct visual depth perception is lost from the position of an observer in the modules. The viewing capability thought to be desirable includes continual direct visual contact with an EVA crewman and with the RMS end effector from the interior, as well as the ability to visually inspect the major elements of the station. From the viewing standpoint, none of the configurations as defined was judged to have the

desired number of windows, but the Delta and "T" were further considered undesirable because the truss structure inherently obstructs some fields of view.

The structural dynamic differences between the three configurations are significant from a control system standpoint; the Building Block concept, in particular, would require a more sophisticated design, with attendant implications on verification, both of the structural math models and the control software. The control and elastic body frequency ranges of the three configurations are presented in figure 3.5-1 to illustrate this point.

The interface and mechanical systems requirements of each of the three configurations are found to be significantly different. The Building Block concept utilizes a universal, although complex, interface between modules to provide all utility connections as well as to perform the structural functions. In addition, a highly complex mechanism is required to connect the oriented solar arrays, antennas, and radiators to the module assembly. This specific interface is expected to require maintenance since it is in continuous use, and no means of performing this maintenance has been identified. This is, in fact, viewed as a major technical challenge associated with the Building Block configuration.

The mechanical and interface systems required with the Delta configuration are essentially all associated with initial deployment or reconfiguration, except for the RMS and berthing systems common to all configurations. The many different mechanisms associated with placement of major elements on the truss structure have not been fully defined, but the number of different systems involved is seen as some disadvantage. However, it is noted that these will each be somewhat simpler than the universal interfaces associated with the Building Block configuration. Notably absent from the Delta is the

STRUCTURAL DYNAMICS AND CONTROL SUMMARY

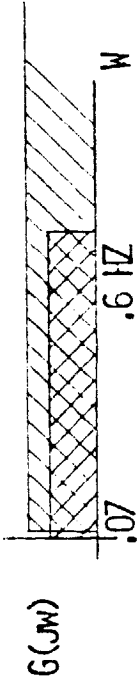
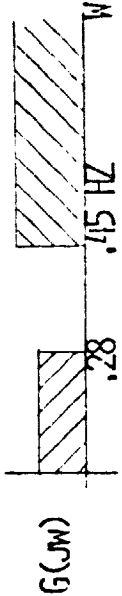
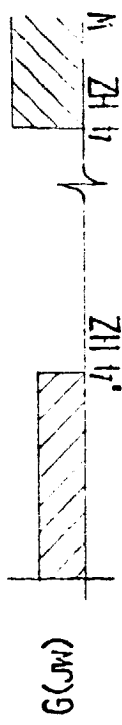

CONFIGURATION	ANALYSIS	REMARKS:
BUILDING BLOCK	 <p>$G(j\omega)$</p> <p>0.07</p> <p>0.6 HZ</p> <p>ω</p>	REQUIRES SOPHISTICATED CONTROL METHODS
"T"	 <p>$G(j\omega)$</p> <p>0.28</p> <p>0.15 HZ</p> <p>ω</p>	MARGINAL SEPARATION PROBABLY REQUIRING VIBRATION FILTERING SLOW TIME RESPONSE
DELTA	 <p>$G(j\omega)$</p> <p>0.1 HZ</p> <p>0.1 HZ</p> <p>ω</p>	SIMPLE RIGID CONTROL
	 <p>CONTROLLER PASSBAND</p> <p>STRUCTURAL DYNAMIC</p> <p>CONTROL/STRUCTURE INTERACTION</p>	

FIGURE 7.5-1

continuously moving interface with the solar array boom. Further, the truss-mounting of all major elements makes the interfaces between modules, and the level of redundancy required to compensate for loss or removal of a module, less demanding. In contrast, the large size of the Delta (and also the "T") requires a longer reach for the RMS, and perhaps the use of more joints in the RMS, arms than does the Building Block configuration.

The "T" configuration, although requiring a mechanism for tilting the solar array truss, shares most attributes with the Delta from an interface and mechanical systems standpoint. Since the rotation of the truss is only through $\pm 17^\circ$, the problems associated with continuously moving interfaces on the Building Block configuration are not present. Further, no moving fluid connections appear necessary. The large truss structures associated with the "T" and the Delta can be considered mechanisms, and an apprehension exists as to the success of the deployment of these trusses. The most significant uncertainty, and hence apprehension, associated with these trusses appears to be in the addition of truss area to an already deployed truss. This operation is required to establish the IOC "T" configuration, and hence, is seen as a disadvantage. However, this same type of operation is also required to expand the Delta to the growth configuration and therefore, also pertains to it.

In the thermal control area, specific differences are found in the required radiator area on the three configurations, as shown in table 3.5-3. These differences are inherent in the configuration, and show an advantage for the Delta. Since the configuration also avoids the necessity for rotary joints in the coolant loops, this is considered significant. The "T" configuration suffers the disadvantage of not only requiring added radiator area for the power modules because of the oversized power module capability, but also

TABLE 3.5-3

THERMAL CONTROL EVALUATION SUMMARY

<u>FACTOR</u>	<u>BUILDING BLOCK</u>	<u>DELTA</u>	<u>T</u>
THERMAL ENVIRON.	25% BLOCKAGE 30 B/H-FT ² ABSORBED	1% BLOCKAGE 20 B/H-FT ² ABSORBED	11% BLOCKAGE 40 B/H-FT ² ABSORBED
RADIATOR * AREA	5346 FT ² (DEPLOY) IOC	4966 FT ² (TRUSS) IOC	9541 FT ² (TRUSS) IOC
ORBITER IMPACT	15% RADIATOR BLOCK.	15% RAD. BLOCKAGE MAIN LANDING GEAR	15% RAD. BLOCKAGE
DESIGN COMPLEXITY	DEPLOYED RAD.	TRUSS RADIATOR INSTALLATION	TRUSS RADIATOR INSTALLATION
CERTIFICATION	GROUND/FLIGHT TESTING	GROUND/FLIGHT TESTING	GROUND/FLIGHT TESTING
SURFACE CONTAMIN.	CAN BE HANDLED	CAN BE HANDLED (LESS OF PROBLEM)	CAN BE HANDLED
COMMONALITY	SIGNIFICANT POTENTIAL	SIGNIFICANT POTENTIAL	SIGNIFICANT POTENTIAL
TECHNOLOGY STATUS	ESTABLISHED OAST PROGRAM	ESTABLISHED OAST PROGRAM	ESTABLISHED OAST PROGRAM

* Total radiating area (excluding body mounted radiators) includes manned base radiators and power systems radiators. Deployed radiators are two sided and truss mounted radiators are one sided.

because the viewfactors of the radiators which reject heat from the modules is poor.

The Delta configuration appears to be preferable from a power system standpoint. The solar array can be expanded in any desired increments, with individual packaged modules consisting of solar array, conversion and storage equipment, and radiator panels. No moving connections are required. The oversizing of the array by 10% to account for Beta angle losses is not a significant penalty. The Building Block configuration, on the other hand, is limited in power growth with planar solar arrays. Rotating joints capable of transmitting conditioned power are required on the Building Block configuration. The "T" configuration, while sharing some of the attributed of the Delta, requires twice the capacity in the solar array and electrolysis units, and to minimize storage requirements, a more complex power control system is envisioned which takes advantage of the power available from the array at low sun incidence angles.

The power profile analysis discussed in 4.12, while not unique to configurations, is noteworthy here in that the power levels required at IOC for operation of the Space Station, exclusive of that indicated to payloads, was found to be on-the-order of 50 KW. Thus, if the payload power levels of 60 KW for IOC and 120 KW for growth are accurate, the IOC station may require 50% more power than currently projected. Some level of power above 150 KW would also be expected for the growth station. On this basis, the practicality of adding power to the station in increments and without severe penalties should be considered an extremely attractive feature. This feature is most evident in the Delta, while it appears to be totally absent in the Building Block configuration. The "T" configuration, while it possesses the

capability of additions to the truss size, may raise the issue of practicality above the 150 KW level simply due to the extremely large cell array required. One other disadvantage to the Building Block configuration is associated with the minimal structure of the deployed solar array and the requirement for the OMV, Orbiter, OTV, etc. to operate in close proximity to the arrays, since they are mounted on booms connected to the module assembly. This disadvantage is that plumes from the RCS of the proximity-operating vehicles will of necessity impact the array at significant incidence angles and at relatively close distances. The resulting forces could disturb not only the solar array blanket, but also the entire, highly flexible structure. Although detailed analysis remains to be accomplished, the resulting motions could cause severe problems with the structure, blanket, and perhaps with vehicle attitude control.

The communications system is shown to be very sensitive to vehicle orientation, highly favoring the velocity-vector orientation of the Building Block configuration and "T" concepts. This derives from the requirement to communicate with proximity-operating vehicles in basically the same orbit. To meet a full time coverage requirement for such communications spherical coverage is required on the Delta. Antenna requirements are summarized in table 3.5-4. Although this is not viewed as a technology problem, some system complexity is added to manage the many more antennas the delta requires in addition to their cost and maintenance requirements. The significant conclusions that can be reached on the basis of the current study seem to be as follows:

1. The design driver of minimum propellant for RCS orbit altitude maintenance appear not to be important in selecting a station concept for the 270 n.m. altitude. If lower altitudes are required, this could alter the propellant usage considerably. Proper design and implementation of any concept appear to be capable

TABLE 3.5-4
ANTENNA REQUIREMENTS SUMMARY

<u>Communication Link</u>	<u>BUILDING BLOCK</u>		<u>DELTA</u>		<u>"T"</u>	
	<u>Number of Antennas</u>		<u>Number of Antennas</u>		<u>Number of Antennas</u>	
	<u>IOC</u>	<u>Growth</u>	<u>IOC</u>	<u>Growth</u>	<u>IOC</u>	<u>Growth</u>
SPACE SHUTTLE ORBITER	1	1	3	3	1	1
MULTIPLE ACCESS LINK	3	3	3	3	4	4
TRACKING AND DATA RELAY SATELLITE	1	1	3	3	1	1
GLOBAL POSITIONING SYSTEM	1	1	3	3	1	1
TELEVISION	2	10	6	18	4	12
ORBITAL TRANSFER VEHICLE	0	2	0	3	0	2
SPACE SHUTTLE ORBITER RENDEZVOUS RADAR	2	2	2	2	2	2
RENDEZVOUS	2	2	3	3	2	2
MULTIPLE TRACKING	0	2	0	5	0	2
	0	2			0	2
	12	26	23	43	15	29

of reducing differences to a negligible level.

2. While the users tend to prefer a velocity-vector, local vertical orientation, an inertially-oriented station appears to be adequate from both the standpoint of user requirements and proximity operations.

3. From the system and subsystem engineering evaluation, the BB and "T" configuration were similar with respect to the communications and tracking function; however, the Delta configuration requires additional antenna for the same coverage.

4. A significant difference from the user and crew operations perspective is that the Delta and "T" place some of the equipment, including observation instruments, significant distances from the pressurized modules. Thus, these configurations imply the use of "long distance" EVA and RMS operations, seen as undesirable.

5. From the standpoint of growth and mission versatility, the Delta and (to a lesser extent) the "T" are seen to be advantageous.

6. Absence of detail in the interfaces between the truss and subsystems, payloads, modules, etc., in the nature of the OMV and OTV hangar structure, and in the RMS, Orbiter, EVA, etc., operations associated with all three configurations appears to be primary impediment to a complete evaluation.

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